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GENETIC PSYCHOLOGY MONOGRAPHS

**Child Behavior, Animal Behavior,
and Comparative Psychology**

EYE-MOVEMENTS AND OPTIC NYSTAG- MUS IN EARLY INFANCY*¹

From the Yale Psycho-Clinic

By

JOHN M. MCGINNIS

*Received for publication by Arnold Gesell of the Editorial Board,
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JOHN M. MCGINNIS

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I

INTRODUCTION

PROBLEM

Oculo-motor responses are important in the development of orientation in space, are important in the development of visual perception of both stationary and moving objects, and are among the earliest complex behavior patterns to become organized and adapted to the infant's environment.

The aim of this investigation is to secure data on the genesis of these responses in the human infant. In order to carry out this aim, the following three aspects of oculo-motor behavior are studied:

- 1) Optic nystagmus.
- 2) The first occurrence of saccadic, pursuit, and coordinate compensatory eye-movements.
- 3) The development of ocular pursuit.

HISTORICAL ORIENTATION

What can we learn from the literature concerning oculo-motor responses in the human infant?

To summarize briefly, we find that the eyes of infants are sensitive to light from birth. This sensitivity is shown by protective responses, such as lid-shutting,¹

¹Sikorski (87, p. 242); Kroner (66, p. 39); Kussmaul (68, p. 35); Heubner (60, pp. 5-6); Peiper (75, p. 13); Major (70, p. 336); Preyer (79); Cruchet (42, p. 49); Bouquet (37, p. 14); Cuignet (43, p. 118); Genzmer (51); Peterson and Rainey (77) (31 children under 6 hours); Gutmann (54, p. 109); Dix (46, p. 1) (eyes closed to an approaching flame on the second day); Scupin (83, p. 1).

even in sleep,² crying,³ and turning away of the head from light,⁴ which are present from birth, even in the case of prematures;⁵ by the pupillary light reflex, which appears soon after birth in case of both full-term⁶ and premature infants;⁷ and by slow and inaccurate, but nevertheless consistent, positive orientation⁸ of the head and eyes to light stimuli not sufficiently strong to evoke a negative response.

Differences between observations of various writers indicate that infants differ greatly in their sensitivity to light, and Gutmann (54) has noted great differences among infants observed by him.

*Optic Nystagmus.*⁹ Bárány (101, p. 140) reports

²Kroner (66); Peiper (75); Canestrini (38, pp. 37-39); Preyer (80); Peterson and Rainey (77).

³According to Sikorski (87); Genzmer (51); Canestrini (38, p. 45); and Gutmann (54, p. 110).

⁴Gutmann (54, p. 118).

⁵Kussmaul (68, p. 35) and Peterson and Rainey (77).

⁶Cruchet (42, p. 49); Kroner (66, p. 39); Kussmaul (68, p. 35); Preyer (78, p. 4); Heubner (60, pp. 5-6); Worth (98, pp. 20-21); Gutmann (54, p. 111); Sherman and Sherman (84).

⁷Genzmer (51, pp. 20-21); Magitot (according to Peiper); Peiper (75, p. 12).

⁸Locke [quoted by Tracy and Stimfl (92, p. 2)]; Tiedemann (translated by Murchison and Langer) (73, p. 206); Genzmer (51); Preyer (80, p. 38); Talbot (89, case C); Kroner (66, p. 39); Kussmaul (68, p. 35); Peiper (75, p. 18); Cuignet (43, p. 118); Sigismund (86, p. 16); Moore (71); Shinn (85, p. 10); Blanton (36, p. 461-462); Watson (94, p. 244-245); Heubner (60, p. 5-6).

⁹This response is the response of the eyes to a succession of moving objects. It consists of two phases: a slow deviation in the direction of the movement of the object, and a rapid jerk in the opposite direction. The slow phase is usually considered to be the same as the Type II (pursuit) eye-movement of Dodge (8). This is the same as the *gleitende* (*langsame*) eye-movement of Gertz (17); and the

that optic (*Eisenbahn*) nystagmus is present in infants only a few hours old. This observation is corroborated by Nasiell, one of Bárány's former assistants, in case of an 8-hour-old infant; but Bartels (103, p. 307) is unable to observe optic nystagmus in

rapid phase is usually considered to be identical with Dodge's Type I and Gertz' saccadic eye-movement [see Borries (107) and Dodge and Fox (122)].

This is a normal response, which should not be confused with the various forms of pathological nystagmus. It has been called *Eisenbahn* (railroad) nystagmus by Bárány and others, *Optotaxien* by Bartels, optomotor nystagmus by Cords and Kestengaum, *Bewegungs-nystagmus* by Cemach and by Cemach and Kestenbaum, *optischen Drehnystagmus* (a misleading and ill-chosen term) by J. Ohm, E. Ohm, and Brunner, experimental optic nystagmus by Brunner and Borries, *optokinetischen Nystagmus* by Borries, and optic nystagmus by Bárány, Wirths, Coppez, Demetriades, Kollner, Borries and Meisling, Stenvers, Ehlers, Wilbrand and Sängner, Fox and Holmes, and Dodge and Fox. The writer adopts this last term.

Helmholtz (125, Vol. III, p. 247) first adequately described this phenomenon in connection with the sensations and eye-movements produced when looking out of the window of a moving train. Bárány (99) applied optic nystagmus, as well as vestibular nystagmus, as a diagnostic aid in a case of "unilateral paralysis of gaze" (*einseitiger Blicklahmung*). Wirths (141) found that the quick component of optic nystagmus was lacking in a case of "*asoziierten Blicklahmung*" to the same side that the voluntary movements were lacking. The same is true of vestibular nystagmus.

Bárány and Wirths both demonstrated that in optic nystagmus the slow phase may persist alone just as in vestibular nystagmus. Coppez (114, pp. 122-126) discusses optic nystagmus and maintains that since optic nystagmus is unconscious (as pointed out by Helmholtz), the cortex does not participate in this mechanism. Bartels (103) observed optic nystagmus in both reptiles and birds, but not in rabbits; in sucklings, but not in newborn infants on the first day; he also found that it occurs very well in idiots. He believes that optic nystagmus occurs involuntarily and unconsciously, that it has nothing to do with the cerebrum, but that it follows the short visual reflex path via the optic nerve and the colliculi to the eye-muscle nuclei. Bárány (101) communicates important data and theoretical con-

newborn infants on the first day. However, Professor Raymond Dodge, Dr. J. C. Fox, and Dr. Marion Putnam, all of Yale University, have made unpublished observations of optic nystagmus in the first days after birth.

Eye-Movements. Unfortunately, writers who have observed eye-movements in young children, almost without exception,¹⁰ have been entirely unfamiliar with the work on eye-movements in adults. As a result, they do not describe their observations in a manner consistent with the classification of eye-movements in adults; and in most cases it is difficult to determine from their descriptions exactly what type of eye-movements is observed.

The only *definite* evidence for the occurrence of *saccadic* eye-movements in young infants is obtained

clusions. He reports the occurrence of optic nystagmus in infants only a few hours old, and makes the following important points: Optic nystagmus is to objective inspection just like vestibular nystagmus, but it is an extraordinarily complicated mechanism for which three different impulses are necessary—(a) the *Fixationsimpuls*, (b) the impulse to follow a moved object, and (c) the jerking back of the eyes in glancing at the object next to be fixated. It is now completely clear to him that the neural impulses for this response do not, as he believed in 1907, arise in subcortical centers, since a reflex for which attention is necessary is involved, and this certainly cannot be thought to come about in the medulla and corpus quadrigeminum, at least, not without the assistance of the cerebral cortex. He also suggests that it would be interesting to know how a central scotoma would affect optic nystagmus.

Since Bárány's paper in 1921 there have been numerous papers dealing with optic nystagmus. They are not summarized here, but are referred to where they are most relevant to the discussion in this paper.

The study of optic nystagmus in this investigation is due to a suggestion made by Professor Dodge.

¹⁰Guernsey (53) is certainly an exception.

from reports of the occurrence of optic nystagmus in newborn infants (see Footnote 9). For the most part, the movements observed have been pursuit movements (Dodge's Type II). The conclusion that this is the case, however, must be based largely on the conditions of stimulation rather than on the descriptions of the responses, due to the inadequacy of such descriptions.

Coordinate Compensatory Eye-Movements. The writer is unable to find a description of the occurrence of this type of eye-movement anywhere in the literature on eye-movements in children.

Looking from One Point to Another. A few writers¹¹ describe the first occurrence of looking from one object to another, but none adequately describe the eye-movements involved in this act. The descriptions given make it impossible to determine whether or not these movements are true saccadic movements (Dodge's Type I), such as occur when an adult looks from one point to another.

Ability to Follow Moving Objects with the Eyes. There are, in the literature, numerous observations concerning the time of first occurrence of the ability to follow moving objects. These are summarized in Table 1.

In spite of the large number of observations which have been made on the ability of infants to pursue a moved object with the eyes, we are unable to come to any very definite conclusions with regard to either the

¹¹Moore (71, Part II, Section 1) 7th day; Preyer (80) 11th day, and in another child on the 14th day; Major (70, pp. 340-341) 16th day; Heubner (60, p. 7) 3rd week; Shinn (85, p. 14) 25th day; Blanton (36) 26th day.

TABLE 1
OBSERVATIONS CONCERNING THE TIME OF FIRST OCCURRENCE OF
THE ABILITY TO FOLLOW MOVING OBJECTS

Age	Number of subjects	Author and reference	Stimulus	Miscellaneous
Soon after birth	1	Ribot (142, p. 11)	light	
Soon after birth	5	Blanton (36)	hand	close to child
8th day	2	Blanton (36)	hand	
8, 18, and 36 hours, 3, 4, 5, 6, 14, 15, 21, and 30 days; <i>failures</i> at 9 hours, 3, 5, and 14 days				
20th hour	1	Blanton (36)	dim light	one-half meter away
2 to 4 days	6	Dearborn (45)	hand and fingers	slow movement
2nd day		Gutmann (54, p. 121)	light	
newborn	?	Drummond (49, p. 16)	bright light	
		Genzmer (51, pp. 20-25)	light or small object	<i>failure</i>
newborn	2	Cuignet (43, p. 119)	light or small object	<i>failure</i>
youngest	2 days old	Genzmer (51, pp. 20-24)	bunch of polished keys	15-degree angle
newborn (first 8 days)	numerous (?)	Kussmaul (68, p. 37)	candle in dark	<i>failure</i>
44 hours, and 7, 8, and 10 days	1	Moore (71)	shiny object in daylight	<i>failure</i>
4 days	1	Scupin (83, p. 2)	hand	slow movement
5 and 7 days	2	Cramausel (41, pp. 1 ff.)	light	one meter distant; followed, but not exactly
5 days	2	Cramausel (41, pp. 1 ff.)	fore-finger	few centimeters from eyes; followed momentarily

TABLE 1 (*continued*)

Age	Number of subjects	Author and reference	Stimulus	Miscellaneous
22 days			light	
25 and 37 days			moving towel	
2nd week	1	Warden, (93, p. 328)	black hat	
15th day	1	Alcott, in Talbot (89)	watch	
3 weeks, 6 weeks	2			
3rd and 4th weeks	twins			
3 weeks	1	Dix (46, p. 14)	object (?) watch	<i>failure</i> 25 centimeters distant
23 days	1	Preyer (79)	candle	slowly moved
32 days	1	Hall (55)	hairbrush in hand	slow movements
5th week	1	Sigismund (86, p. 34)	pendulum of clock	response not described in detail
9th day	1	(observed by nurse)	hand	
33rd day	1	Shinn (85, p. 14)	candle	
40th day	1	Shinn (85, p. 14)	moving person	
31st day	1	Dearborn (45, p. 18)	fingers and watch	30 inches from eyes
21 days	1	Rasmussen (82, p. 44)	fingers	<i>failure</i>
82 days			mirror slowly moved sideways	<i>success</i>
33 days	1	Jones (61) (best response among 300 subjects)	light	moved horizontally through a distance of 2 feet, at one foot
58th day	300	Jones (61)		50th percentile of group
4 months		Gesell (52, pp. 100-101)	moving plate	83% succeed

time at which this ability first occurs, the exact nature of the response, or the effect on the response of changes in the experimental conditions.

Most of the literature dealing with the development of this ability consists of rather casual observations on individual children. For the most part, neither the responses nor the conditions of observation are adequately described. These same criticisms also apply to some of the investigations dealing with a number of children.

However, a few of the older and some of the more recent investigations are well controlled. Jones (61) carries out an investigation under carefully described and fairly well controlled conditions, but unfortunately she does not describe the number and type of eye-movements occurring during ocular pursuit; as a result one is not certain as to the exact criterion which she uses to differentiate between a successful and an unsuccessful response.

Guernsey (53) is the only experimenter who does describe completely the number and type of eye-movements occurring during ocular pursuit of an object moved at known speeds, during ocular pursuit of an object moved at accurately controlled speeds, and under controlled conditions.

Some Factors Influencing Ocular Pursuit (based on a survey of literature).

Speed. The speed of the stimulus appears to be of the utmost importance in determining the degree of difficulty involved in following a moving object.¹²

¹²Hall (55), Darwin (44), Preyer (79), Shinn (85), and Moore (71) point out the fact that a child is unable to follow rapidly moving objects as early as he can follow slowly moving ones; and most observers who report successful pursuit in young infants specify that the object followed moves slowly.

There is general agreement, although the number of observations is limited, that the ability to follow rapidly moving objects does not appear until quite late.¹³

Direction. Jones (61) has shown quite definitely, with over 300 subjects, that the ability to follow a light moved horizontally appears before the ability to follow one moved in a vertical direction, and the latter ability, in turn, appears before the ability to follow the same light moved in a circle under the same conditions.

Extent. The space traversed by the light in Jones' experiments [two feet at a distance of one foot—if we interpret her description correctly (61, p. 548)] represents an angular distance of 90 degrees. It seems possible that younger infants might be able to pursue successfully an object moved through a smaller angular distance.

Size. The results of studies of fixation in adults (11, esp. p. 10, 26ff.) show that small bright objects (such as have been used in most experiments with children) cannot be fixated as accurately as large ones; and Genzmer's (51) experiments suggest that the child is able to follow a large object earlier than he is able to follow a small one. A confirmation of Genzmer's results would suggest that the extra-foveal portions of the

¹³It is desirable that the speed of the object be stated in terms of visual angle. For example, the speed of movement of the light used by Jones (61) (1 foot in 2 seconds) might seem to be quite slow, and its pursuit seems to represent an easy task. However, this speed is equivalent to an average angular speed of 22.5 degrees per second. It seems possible, even probable, that children could follow at an earlier age a light moved at a slower angular speed.

retina have an important function in the ocular responses of the young infant. This would be opposed to the theory, first suggested by Cuignet (43, p. 119), that the fovea is the only portion of the retina functioning in the newborn infant.

Brightness. Most previous experimenters have used candles, lights, lamps, shiny objects, faces, towels, hand and fingers, a watch, a plate, and other bright objects as stimuli. However, Warden (93) reports successful pursuit of a black hat during the second week, and it is possible that other less bright objects could be followed successfully.

PRELIMINARY EXPERIMENTATION AND DEVELOPMENT OF TECHNIQUE

We are faced with three main tasks: (*a*) to develop a satisfactory technique for recording the eye-movements of infants; (*b*) to devise an experimental situation which will produce consistent oculo-motor behavior in the child; and (*c*) to apply the recording technique to the experimental situation without interference with either.

SURVEY OF EYE-MOVEMENT-RECORDING TECHNIQUES USED WITH ADULTS; AND THEIR APPLICABILITY TO INFANTS

A survey of the techniques¹⁴ which have been used to

¹⁴For good summaries of eye-movement recording techniques see Huey (18, pp. 285-286), Dodge (8, pp. 308-310; 12), Coppez (114, pp. 8 ff.), Miles (24), and Tinker (32, pp. 74-89). Tinker's account is the most complete, and is up to date, but Coppez gives some additional references, especially to methods used in recording nystagmus.

record eye-movements in adults shows that these methods may be grouped under a few headings:

1) *The After-Image Method*. This method obviously cannot be used with infants.

2) *Methods Involving Attachment of the Recording Apparatus Directly to the Eyeball*.¹⁵ These methods are clumsy, often inaccurate, uncomfortable, and even dangerous. Their use with infants is contraindicated.

3) *Methods of Recording Eye-Movements through the Wholly or Partially Closed Lids*.¹⁶ The difficulties involved in applying this method to an infant while awake, the fact that it involves keeping one eye closed, and the fact that approximate head fixation is a prerequisite, eliminate this method from consideration as far as our problem is concerned; but this technique appears to have possibilities for the recording of vestibular nystagmus in young children, and possibly for recording certain eye-movements during sleep.

4) *Yourievitch's Ocular Cinegraph* (34, pp. 499-501) was not known to the writer at the beginning of the investigation, but records secured by this method are not accurate, since they confuse movements of the lids and of the muscles around the eyes with movements of the eyeball. Also, this method does not meet the particular requirements of this investigation.

5) *The Corneal Reflection Method*. This method,

¹⁵Used by Ahrens, Orschansky, Delabarre, Huey, Marx and Trendelenburg, Struycken, Bartels, and Ohm.

¹⁶Used by Wells, Purkinje, Breuer, Lamare, Ohm, Buys, Schackwitz, Galley, Wojatschek, Majewski, Dodge, and others, in various forms.

originally developed by Dodge and Cline (14), offers many advantages as an eye-movement-recording technique, but its application to infants and young children offers difficulties. The greatest difficulty is that corneal reflection records are only valuable when the head is held almost or exactly stationary.

Other disadvantages of this technique are that the recording light, producing the image reflected from the cornea, serves to distract the child from the stimulus, and also is necessarily so bright that it will produce lid-shutting and other defensive reactions on the part of a young infant. Of course it should be remembered that head fixation is desirable in case of all eye-movement-recording methods, including even direct observation and the use of moving pictures, although not so necessary with the latter technique as with the corneal reflection method.

Preliminary attempts using this technique are unsuccessful with children below three years because satisfactory head fixation is not secured, hence the method is discarded.

6) *Recording by Direct Observation, with the Aid of Magnification.* The simplest method of this type consists in placing strong (20 diopter or over) convex glasses (Bartels' glasses) on the individual whose eyes are being studied. The observer then sees a greatly enlarged image of the eye. This method interferes with the vision of the subject, making fixation impossible, and in no way satisfies the needs of the present investigation.

Erdmann and Dodge (15) use a telescope with a crosslined field, Ohrwahl (27) focuses a telescope on a

corneal blood vessel, and Guernsey (53) uses a standard differential pupiloscope for observing pupillary reflexes and eye-movements in children. The use of such optical instruments to secure a magnified image of the eye offers many advantages, and a careful observer can learn much by this method. It has the advantages of being inexpensive, of requiring only a moderate degree of illumination, and of being very easily adapted to various experimental situations. On the other hand, it is a subjective method, and its use is limited by the accuracy of perception and memory of the observer.

7) *Motion Picture Recording.* Methods making use of white spots applied to the cornea as reference points¹⁷ are contra-indicated for work with infants, because, in addition to the difficulty of application and removal, their use involves some danger of irritation and infection.

Moving picture records of eye-movements, without the use of "eye-spots" are less accurate, but are used in studying nystagmus, first, by Coppez in 1910, and a little later by Pinaroli [see Coppez (114, p. 16)]. Pinaroli enlarges his most satisfactory series of negatives, and then applies a transparent checker-board of mm. squares to each frame, inscribing the position of the eye on the squared surface, and thus obtaining a graphic representation of the movement. He uses the lower part of the cornea as a reference point. Judd and his students project their records on a screen, at life size, and plot the eye position frame by frame.

¹⁷Judd, McAllister, and Steele, (21), and other studies by Judd and his students; also Totten (33).

This latter technique offers advantages over that of Pinaroli.

Totten (33) uses eye-spots in studying eye-movements in animals.

Jones (61, p. 556) suggests that the use of moving pictures or a falling-plate camera would be valuable in studying the detailed characteristics of the eye-movements involved in the pursuit of a light moving in a circle. The suggestion of the use of these techniques to study the eye-movements of infants is a good one, although the falling-plate camera is not well adapted for recording circular eye-movements.

After careful consideration of all known eye-movement recording techniques, cinema recording is adopted. Although cinema records are less accurate, less convenient, and more expensive than records obtained by the corneal reflection method, the technique adopted offers definite advantages. It is freer from technical difficulties during the period of experimentation than is the other; it interferes less with the response of the child to the stimulus situation; and *the records include a larger proportion of the total response of the child than do those secured by the corneal reflection method.* Cinema records include, in addition to the movements of the eyes and head, valuable data concerning eyelid responses, hand, and mouth behavior, and expressive responses of the facial musculature.

Cinema records also have a number of advantages over even the best methods of direct observation. The principal one is that they furnish an accurate, permanent, and objective record of the response, which

can be studied over and over again, at any time, and by any one. This allows the observation of many points which could not possibly be noticed and recorded by direct observation; and also allows the demonstration of these points to others for educational or scientific purposes.

Cinema records are especially advantageous for a genetic study in which it is necessary to compare a response made today with one made a day, a week, a month, or a year previously, because one can study, within a few seconds of each other, bits of behavior which occur on widely separated dates.

PRELIMINARY EXPERIMENTS

The first situation used consists of a ground-glass screen, placed in front of the child, on which a spot of light is projected from behind; then, after a period of from 1 to 4 seconds, the first spot of light disappears, and one similar in size and intensity appears in a different location. The sequence and duration of these lights is controlled automatically by means of five brushes which move in a spiral over a kymograph drum and make contacts with it through perforations in a tough paper covering of the drum surface. Children six months of age and older respond very actively to this situation, looking from one spot of light to the succeeding one.

The next problem is to adapt this situation for moving picture recording. This is done by placing eight 100-watt lamps back of the frame holding the ground-glass screen, out of sight of the child observing the screen; and by focusing this light, by means of

especially designed reflectors, on the infant, whose head is placed 18 inches in front of the center of the 2-foot-square ground-glass screen. These reflectors are made of celloglass screening, and are painted a flat white. As a result of this arrangement, diffuse indirect illumination, of sufficient strength for successful photography, is thrown on the subject.

Recording is now possible, but so much light is reflected indirectly onto the ground-glass screen, that its surface is quite bright, and light spots no longer "stand out" in contrast with their background. The situation calls for a screen which will reflect a minimum of light, and allow a maximum amount to pass through from the stimulus light sources behind it. In other words, a screen is needed which looks black when illuminated from the front, and white when illuminated from behind. In addition, the apertures in the black box just behind this screen, through which the stimulus lights pass, must be entirely invisible except when the light is passing through them.

A screen which satisfies these requirements is made from a piece of ordinary ground glass.¹⁸ The front surface of this screen is dark enough so that

¹⁸The smooth surface is uniformly ground by means of another piece of glass and a moderately fine grade of emery powder moistened with water. The original surface is then covered rapidly with a coat of quick-drying, flat black paint (Murphy's Dacote). This is wiped off as quickly and as completely as possible, with clean dry cheese-cloth, and the glass is then allowed to stand. A few hours later this procedure is repeated a second time, and still later, a third time. The smoother surface, ground with the emery powder, is given two similar treatments, except that flat white paint is used, and then the screen is returned to its frame, with the black side toward the subject.

the stimulus lights contrast effectively with the background, even when the photographic lights are turned on, and when the stimulus lights are turned off there is absolutely no indication as to the places at which they will appear on the screen.

An accessory apparatus¹⁹ produces harmonic motion of a spot of light, of the same size and intensity as that used previously on the screen, in the horizontal plane with respect to the observer. The light moves one way, through a visual angle of approximately 29 degrees, in 1, 2, or 4 seconds, at will. This is later changed to 20 degrees so as to be comparable with the movements of the cylinder which is described later.

Preliminary experimentation with a few children suggested that the ability to look from one spot of light to another may develop later than the ability to follow a moving spot of light through the same angle, that a slowly moving light can be followed earlier than a faster moving one, that the responses are more consistent in either case, and usually occur earlier when the photographic lights are off than when they are on. (The contrast between the spot of light and the background is considerably greater when the photographic lights are off.)

In general, the responses in these situations are very inconsistent. The child "stares" for a long time at some stationary portion of the experimental environment, instead of reacting to the moving stimulus light.

¹⁹Consisting of a spring-driven phonograph motor, pulleys, and a large wheel with an excentrically placed pin which passes through a driving rod, the other end of which is attached by a hinge to a rod which works easily over rollers, and carries the stimulus light.

This experimental situation, while offering a number of advantages, does not produce sufficiently consistent responses on the part of the young subjects. It is very difficult to tell whether the lack of a response is due to the lack of the capacity to make it, or to the fact that the child is responding to some other portion of the environment. This situation seems to be less satisfactory the younger are the children.

The main source of difficulty in the situation just described is the tendency of the children to respond to some stationary portion of the environment, instead of to the moving portion.

Therefore, the apparatus finally adopted is designed so that everything the child can see is moved, and no matter where he looks, he has the opportunity to follow the movements of the visual field if he is able to do so.

II

APPARATUS, PROCEDURE, AND SUBJECTS

APPARATUS

In its final form the apparatus consists of a cylinder (*a*), so supported on a bearing at the head end (*b*) as to move freely about its horizontally lying axis (see Figures 1 and 2). Except for an opening $1\frac{1}{4}$ inches wide which extends around the cylinder at a point midway between the ends, and is covered with 12-mesh screen wire, the cylinder is lined with white cardboard (*c*), to which are attached 11 black cardboard bars (see Figures 1 and 3*a*).

The child is placed dorsally in an especially designed crib (*d*), which is pushed into the cylinder. The cylinder can either be rotated about the child, setting up the conditions of stimulation suitable for the production of optic nystagmus, or oscillated about its axis in harmonic motion, setting up experimental conditions suitable for the study of ocular pursuit (*e*).

The experimental situation is adapted to moving picture recording by placing strong lights (*f*) at both ends of the cylinder, screened from the direct view of the child (*g*), and by building a substantial support (*h*) for the camera (*i*), which takes pictures through the above mentioned opening in the cardboard lining of the cylinder. Perfectly synchronized records of the movements of the apparatus are secured on the cinema records of the child's responses by means of a simple recording arrangement (*j*).

a) The cylinder is 24 inches in length and approximately 25 inches in diameter. Its head end consists of a bicycle wheel and axle, while the framework for the other end of the cylinder is a bicycle rim with the spokes removed. The surface of the cylinder is made of $\frac{1}{4}$ -inch-mesh wire screening, strengthened by four small iron rods, placed 90 degrees apart, and extending the length of the cylinder.

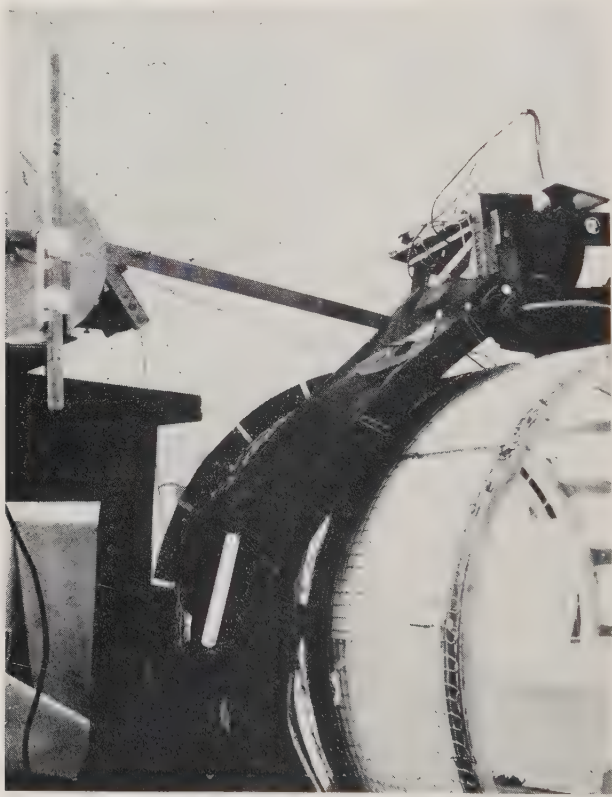


FIGURE 1
PHOTOGRAPH OF THE APPARATUS

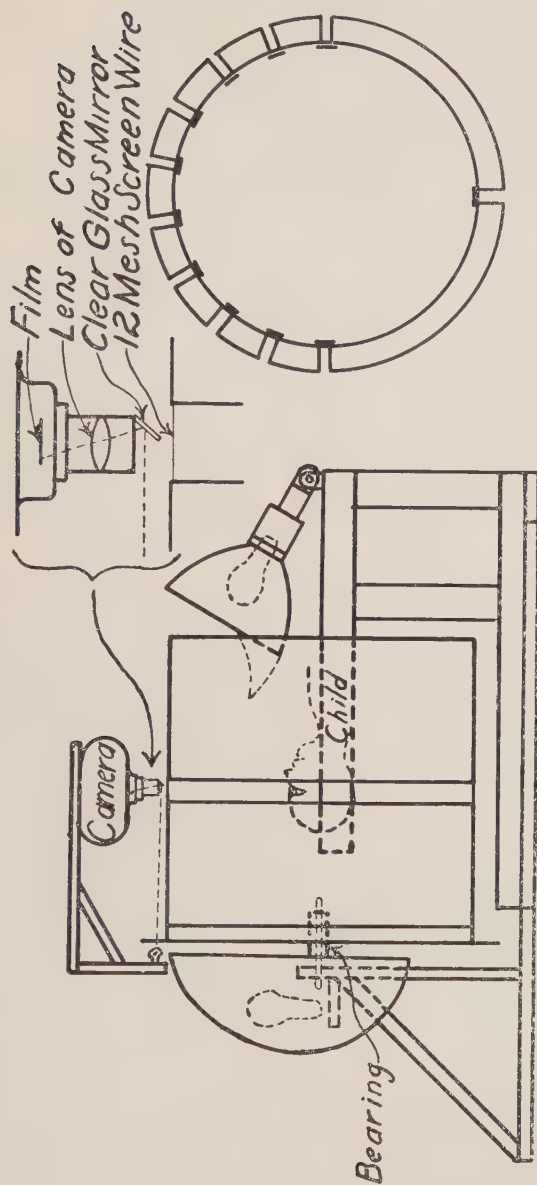


FIGURE 2

DIAGRAM OF THE APPARATUS*

*The arrow indicates the portion of the diagram which is shown enlarged.

b) The axis of the cylinder is fixed firmly in position in the following manner. The threaded axle of the bicycle wheel extends a short distance on the side away from the cylinder, passes through a strong vertical support, and is held in place by a nut. The height of the axle is such that there is a 4-inch clearance between the bottom of the cylinder and the floor. The vertical support mentioned above is attached by screws to a substantial frame built of boards, 1 inch thick and 4 inches wide, which lie flat on the floor.

c) The inside of the cylinder, except for the opening mentioned above and below, is lined with heavy white cardboard, which is extended across the opening at one point (corresponding with bar Number 10) for a distance of 1 inch. Black cardboard bars, $1\frac{1}{16}$ inches wide, running lengthwise of the cylinder, are attached to both cardboard lining and wire mesh by brass paper fasteners with flat black heads. The bars are cut away where they cross the opening in the cardboard lining. The two ends of the latter overlap, for a distance of 1 inch, close to the 10th bar, and are fastened by four paper fasteners similar to those holding the bars. There are 11 bars, each subtending an angle of (almost exactly) 5 degrees (measured from the center of the cylinder). Ten of them are placed on one side of the cylinder, with 20 degrees between their centers, while the 11th is placed at the midpoint of the opposite side of the cylinder (see Figure 3).

When the child and crib are in position, the opening in the cardboard lining of the cylinder (which is filled by a strip of 12-mesh wire screen, painted white on the

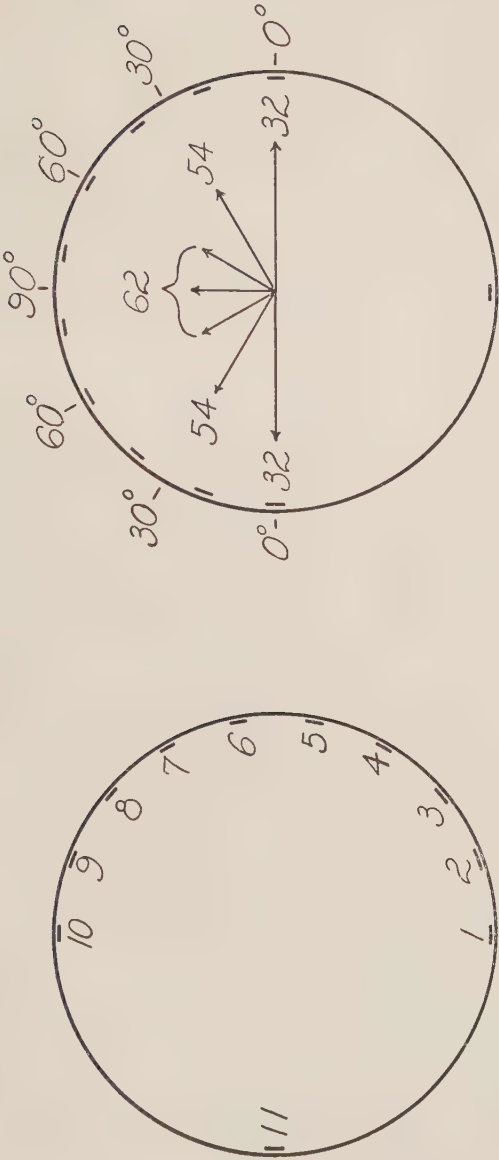


DIAGRAM B
Illumination

DIAGRAM A*
Position of the Bars

FIGURE 3
*When rotated, the cylinder moves clockwise as viewed from its foot, and from the child's right to his left.

side toward the child only, and placed between the cardboard lining and the cylinder proper) comes between the camera lens and the eyes of the child. The amount of light reflected from the brightly illuminated white surface of the screen wire²⁰ is so much greater than the amount reflected from stationary objects which lie beyond the screen wire (the black camera and the black cloth) that the latter are practically invisible from inside the cylinder and do not affect the child's responses.

The camera lens is placed close to the screen wire so that the only effect of the latter on photography is to reduce slightly the amount of light reaching the camera lens, thus necessitating the use of a somewhat larger opening of the diaphragm. The black outside surface of the screen wire and black cloth curtains reduce to a minimum the light reflected from the outside of the screen wire into the camera.

Viewed from the inside, the cylinder consists of a relatively uniform white surface, broken by 11 longitudinal bars, spaced as stated above, and broken in the center by a light gray ring, where the white-painted surface of the above mentioned screen wire is seen.

d) The crib consists of two principal portions—a frame which rests on the floor, and the crib proper. The latter is so attached to the former by stout supports located near its foot, that when the crib proper, containing the child, is inserted head end first into the

²⁰The principle of this screen was originally suggested by Professor Raymond Dodge, of Yale University, and has been applied for different purposes at the Yale Psycho-Clinic. See Gesell (52*a*, pp. 30-36) and Halverson (56).

cylinder, movements of the latter are not hindered. The crib proper consists of a padded rectangular wooden frame (inside dimensions 28 inches by $9\frac{1}{2}$ inches) with a canvas cover. A pencil mark on the cover, at the level of the child's eyes, indicates the proper longitudinal position of the child in the crib. The position of the crib with respect to the cylinder is kept constant by means of wooden guides and stops, which are attached to the wooden frame to which the support for the cylinder is attached. The canvas is attached securely but loosely, and the padding is arranged so that a soft and more or less form-fitting canvas trough, $2\frac{1}{2}$ inches deep, is formed. This is made narrower and is heavily padded where the head is placed, with the result that, although the infant is perfectly free to rotate his head as far as he desires, or to move it sideways slightly, he is unable to move his head out of the field of view of the camera.

Since the longitudinal axis of rotation of his head is approximately the same as the axis of the cylinder, the distance between the child's eyes and the nearest part of the cylinder surface remains practically constant, even when he turns his head far to the side.

The fact that the child's eyes are not exactly at the center of the cylinder complicates our angular measurements somewhat. The bars on the cylinder subtend an angle of 5 degrees as measured from the axis of the cylinder, and an angle of 6.1 degrees as measured from the eye. The distance between the centers of the bars on the cylinder surface is 20 degrees, but in terms of "visual angle" it is 24.4 degrees. The distance through which the cylinder moves when oscillated is 16.45

degrees, or 32.90 degrees when measured from the center of the cylinder, but 20 degrees or 40 degrees when stated in terms of "visual angle." (Of course, all values given for visual angles are approximations. The actual angle will vary somewhat with the size of the child's head, and the exact position of the latter in the crib.)

When describing the angular movements of the *oscillating drum*, *visual angles* are used, in order to allow comparison with other studies of ocular pursuit; but when describing the angular movements of the rotating drum it is simpler to use measurements taken from the center of the drum, and we have adopted this procedure. At first glance one might think that this complication could have been prevented by placing the child's eyes at the center of the cylinder. But in that case head-movements would change markedly the distance from the eyes to the cylinder surface, thus changing to an unknown degree the visual angle subtended by objects on the cylinder surface.

e) The cylinder is turned in the following manner: an Edison phonograph motor turns a small pulley, over which runs a belt to the outside of the cylinder, close to the head end. The tension on the belt is kept constant by means of a belt tightener. The drive pulley is geared to the motor in such a manner that the drive pulley can be "thrown out of gear," or placed in "low" or "high" gear; the ratio between the two being 2 to 1. This arrangement, and the use of two adjustments of the governor of the motor, make it possible to rotate the cylinder clockwise in approximately 9, 18, or 36 seconds, thus giving the surface of the cylinder

a speed of 40, 20, or 10 degrees per second. It should be noted that these figures are *not* equivalent to 40, 20, or 10 degrees per second in terms of visual angle—(see above). The cylinder can also be moved independently of this motor, without removing the belt. The latter arrangement is very convenient, as it allows a comparatively rapid change from rotation to harmonic oscillation of the cylinder surface.

The cylinder is oscillated about its axis by means of the following arrangement. A second phonograph motor drives two small pulleys whose diameters are in the ratio of 1 to 2, and either of these, in turn, is belted to either of two larger pulleys whose diameters are in the ratio of 1 to 2. This motor is so regulated that, by shifting belts, the larger pulleys can be made to rotate in 2, 4, or 8, seconds. An excentrically placed pin attached to the large pulleys passes through a hole in one end of a light drive rod, whose under side carries, near the other end, several short projections which engage the wire mesh on the outside of the cylinder. The position of the excentrically placed pin is such that the drum moves 20 degrees (as measured from the eye of the subject). There is another removable pin, which can be so attached to the apparatus as to give a movement of 40 degrees, measured in the same way. The movement produced, while not perfect harmonic motion, approximates it very closely.

By means of a few quickly made adjustments, the same driving apparatus may, if so desired, be used to move a spot of light on the ground glass screen of the apparatus used in preliminary experiments at a speed

identical with that of the drum (measured in terms of visual angle).

f) In order to secure adequate illumination for photography, without having the light sources come within the child's visual field, lights are placed at the ends of the cylinder, screened from the direct view of the child, and the child's face is illuminated by the light reflected from the inside cylinder surface. A 500 watt clear-glass, mogul-base, incandescent lamp is placed 6 inches beyond the head end of the cylinder with its filament 5 inches higher than the middle of the cylinder. A 200-watt bulb, with its filament $5\frac{1}{2}$ inches away from, and $1\frac{1}{4}$ inches lower than that of the 500-watt bulb, is placed on each side of the latter. A small metal reflector is placed behind the central bulb, and a large curved "celloscreen" reflector, which extends on all sides to within approximately 1 inch of the head end of the cylinder, is placed back of all three bulbs.

The top of a translucent screen of tracing cloth, as wide as the crib, and 8 inches slant height is located directly above the head end of the crib, while the bottom edge of this screen is level with the top of the crib, but $2\frac{1}{2}$ inches beyond its end (see Figure 1). This screen makes it impossible for even the most active infant to look directly at the bulbs placed at that end of the cylinder, while another screen, attached to the reflector at the foot of the crib, has a similar function.

Objective values for the illumination of the drum are secured with a General Electric Foot-Candle Meter. Since the shape and construction of the ap-

paratus make it difficult to secure accurate readings of the illumination at the drum surface, and since we are primarily interested in the intensity of the light to which the eyes of the child are exposed, it seems legitimate to place the Meter at the position ordinarily occupied by the child's eyes. Since the illumination here depends on the light reflected to this point from all parts of the drum surface, the reading of the instrument represents an approximate average of the light reflected from the inner surfaces of the drum to the instrument. The correctness of this line of reasoning is substantiated by the fact that readings of the instrument in the same position are markedly affected by the bars in the visual field. When the Foot-Candle Meter is placed horizontally (facing the vertical), the reading is 62 foot-candles with the group of bars uppermost, but with the single bar uppermost, the reading is 72 foot-candles.

Tests of the effect of external changes in illumination and of possible fluctuations in the electric current used on the illumination in the experimental situation fail to show any differences large enough to be detected by the photometric technique used, hence it seems safe to conclude that the illumination in the experimental situation is constant.

Variations of illumination in different parts of the experimental situation, tested by readings taken with the Meter placed horizontally, and at angles of 30, 60, and 90 degrees to each side, show that the illumination in the apparatus is brightest at the top, and decreases gradually toward each side, as indicated in Figure 3*b*. The numbers inside the circle represent the readings

of the Foot-Candle Meter when facing in the directions which are indicated by the arrows and by the angular measurements given outside the circle. One wonders if the distribution of the illumination in the cylinder is a factor in the tendency of the infants, during the first two weeks, to look toward the sides, rather than toward the top of the cylinder.

h) A substantial camera support is made of brass pipe and includes two semicircular pieces to which the camera carriage is attached by means of four large screw eyes. These semicircular pieces are so placed over the cylinder that their centers fall on its axis. Their diameter is such that when the camera carriage (which is a wooden L-shaped support, cut out to fit the camera and fitted with a camera tripod screw which holds the camera firmly, but allows the photographer to shift the aim of the camera slightly to either side) and camera are attached and the cylinder rotated, there is a clearance of approximately $\frac{1}{4}$ inch between the lowest point of the clear-glass mirror (to be explained below) attached to the nose-piece of the camera, and the highest projections on the outside of the cylinder, which might strike the mirror.

i) A Bell and Howell Filmo camera, equipped with a 1-inch F 1.9, Dallmeyer anastigmat lens, is used. During the early part of the experiment Agfa 16-mm. Cine-film is used, but beginning with the tenth film, Eastman 16-mm. Panchromatic Safety Film is used. The superior results obtained in our experimental situation with the latter film justify the additional cost.

j) A cardboard flange approximately $1\frac{1}{4}$ inch

high completely encircles the outside of the cylinder at the head end. A narrow radial slit is cut out of this flange at the point corresponding to the center of each of the stripes on the inside of the cylinder. The flange is located between a flashlight bulb, which is attached to the short arm of an L-shaped support fastened securely to the back of the movie camera, and a clear glass mirror, which is firmly attached by means of a removable harness to the nose-piece of the camera, at an angle of approximately 45 degrees. Whenever a cut (corresponding to a bar on the cylinder lining) in the above mentioned flange comes between the flashlight bulb and the mirror, the light strikes the mirror, which is attached at such an angle that the light is reflected through the lens of the camera, and the image of the bulb is recorded on an unimportant portion of the film (on the picture of the child's chin). The bulb is placed at the same distance from the camera lens as the subject to be photographed, so that its image is in focus on the film.

The mirror mentioned above is only $\frac{1}{4}$ inch wide and covers only a small portion of the lens; and since it is clear glass, most of the light reflected from the child's face onto the mirror passes through the latter into the camera. Therefore the mirror reduces only slightly the intensity of the photograph of the child. Also, the clear glass mirror does not reflect enough light from objects which are outside the cylinder (less bright than the flashlight bulb) to have an appreciable effect upon the picture.

PROCEDURE

Since the infants are on a regular schedule with regard to food, sleep, baths, etc., on first thought it seems desirable always to carry on the experimentation at a certain time of day. However, experience with the first subjects indicates that the favorable times of day for experimentation (i.e., periods when the child is wide awake and not crying) vary greatly not only in the different children, but in the same child from day to day.

As a result, during the first two weeks, experimentation is carried on whenever the infant appears to be in a favorable condition for it; while after the fourteenth day, the experiments are carried out during the first favorable opportunity on the day on which they are scheduled. After the second week, the procedure is gone through on the 21st, 28th, 35th, and 42nd days. With a few exceptions mentioned below, the maximum deviation from this schedule is one day. See Table 2 for a record of the days on which photographs are taken, the length of time the child is in the experimental room, and the number of feet of film used.

In the first two weeks, it was impossible to go through the entire procedure at one session, so part is carried out at the first favorable opportunity, and the rest at the next opportunity, which may not occur until several days later. Whenever possible, the medium speed of rotation and the medium speed of oscillation of the cylinder are repeated during both sessions, in order to give a basis for comparing the responses on the different days.

After the third week, in order to save film and reduce expenses the slowest speed of rotation and the slowest speed of oscillation are eliminated. (The elimination of the former proves to be desirable, but elimination of the latter is probably a mistake. If the slow oscillation situation had been used during the entire investigation, the data would be of value.)

The slow speed of oscillation of the field of ten bars through an angle of 40 degrees (40 degrees of visual angle in four seconds) is not commenced at the beginning of the investigation; and therefore is not used with all subjects.

The following is a brief account of the exact procedure followed in working with a child. Either *E*, or one of the nurses, observes that the child is awake and quiet in the nursery. Unless it is within a few minutes of feeding time, the child is "changed" by one of the mothers, carried to the experimental room, and placed in the crib portion of the apparatus. A triangular shaped piece of adhesive tape, which serves as a convenient reference point for studying head-movements, is stuck on the subject's forehead, just above his nose. The photographic and recording lights are turned on, and the crib containing the child is pushed into the apparatus, where he cannot look out. This transition from the "room situation" to the "experimental situation" is made slowly and carefully, in order to allow the child to adapt himself gradually to the illumination of the latter situation, and in order to minimize the possibility of an emotional disturbance.

Once in the cylinder, an attempt is made to get the subject to look toward the single bar, which is immedi-

TABLE 2
DAYS ON WHICH PHOTOGRAPHS WERE TAKEN, LENGTH OF TIME
THE CHILD WAS IN THE EXPERIMENTAL ROOM, AND NUMBER OF
FEET OF FILM USED

Age in days	Dorothy R. Time* Film	Harold C. Time Film	Anna M. Time Film	William N. Time Film	Carolyn A. Time Film	Raymond C. Time Film
0		10	4			
1					10	4
2					10	28
3				15	5	17
4						
5			10			
6			39			
7		10				
8		50				
9		23		10		15
10						
11						
12						
13		15				
14	7	5				
15	10	29		15		15
16	20		10	15		82
18	10		37	15	15	
20	10		6		66	
21	15				14	
22						
27		15	20	15	20	15
28						
29						
25†	24	20	15	15	39	10
		35	24	20		40
			9	18		
				47		

TABLE 2 (*continued*)

Age in days	Dorothy R. Time* Film	Harold C. Time Film	Anna M. Time Film	William N. Time Film	Carolyn A. Time Film	Raymond C. Time Film
34						
35	15	51				
36		20	33	15	42	
38		10	16			
41						
42	15	30	?	32		
43		5	29	10	49	15
					25†	40
						40
						20
						38

*This represents the total time (in minutes) in the room. Usually less than half of the time is spent in actual experimentation, and the camera is never run over one minute at a time or more than 3½ minutes during one experimental period.

†Supplementary experiments are tried after the regular procedure is finished.

‡Experimentation is divided into three different periods, all on the same day.

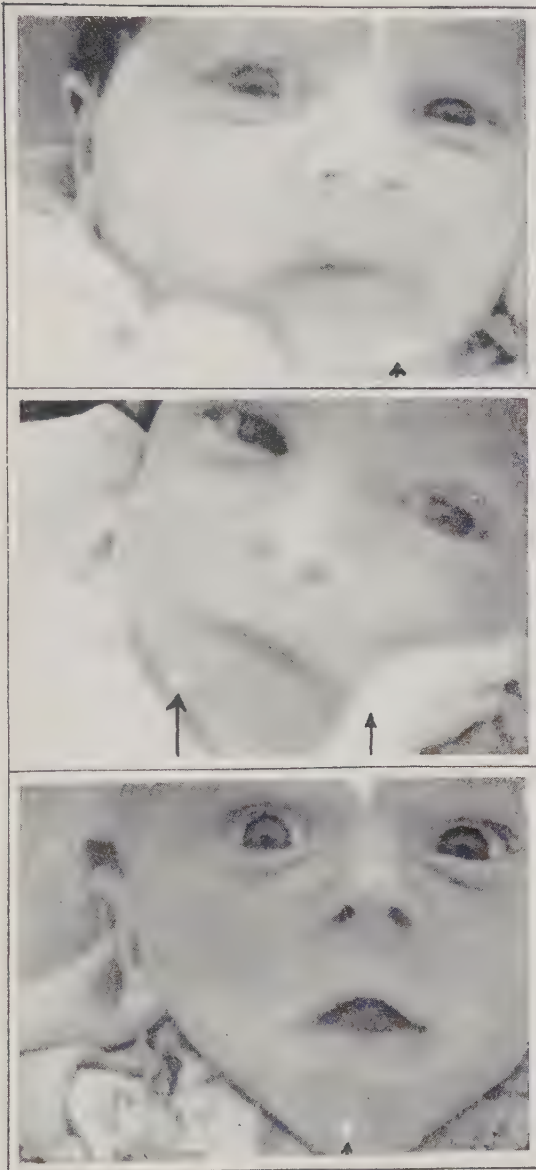
ately overhead; and the spontaneous behavior of the child in this situation, with the cylinder stationary and one recording light on, is photographed for five seconds or longer.²¹

The cylinder is then oscillated (see Figure 4A) at slow speed, and photographs taken. Next, the cylinder is stopped, turned over, the driving rod attached again, both recording lights turned on, and the cylinder is again oscillated at the same speed, but with the 10 bars uppermost, and in the field of vision (see Figure 4B). Following this, the crib is pulled out of the apparatus, while the belt, driving rod, and recording lights are adjusted for the medium speed of oscillation with the single bar uppermost. The crib is again placed in the cylinder, the motor is started, and the response to this situation is photographed. Then the cylinder is again turned over, the recording lights changed, and the responses to the medium speed of oscillation of the field of 10 bars are photographed.

Following this, the camera is wound, and the apparatus is set so as to produce a movement of the barred field through an angle of 40 degrees in 4 seconds, and the responses of the child, as well as the records of the movements of the cylinder, are photographed.

The camera is again wound, the driving rod and oscillation recording lights are removed, the light for recording rotation is turned on, and the second motor is started, rotating the cylinder at slow speed. As Bar

²¹This procedure is not carried out during the earliest examinations of the first subjects, although an equivalent length of time is given to allow the child to become adapted to the new situation before the cylinder is moved.



A

Carolyn A, age 15 days, taken while the apparatus was oscillating with the single bar uppermost

B

William N, age 21 days, taken while the apparatus was oscillating with the group of 10 bars uppermost

C

Raymond C, age 84 days taken just as a bar passed the camera during the rotation of the cylinder

FIGURE 4

METHOD OF RECORDING MOVEMENTS OF THE APPARATUS*

*The photographs are unretouched enlargements from 16 mm. moving picture film. The arrows point to spots of light which serve as signals and record the movements of the apparatus.

10 passes the camera for the first time, the camera is started, and not stopped until Bar 10 passes the camera the second time. As each bar passes the camera a spot of light is photographed for an instant (see Figure 4C). The camera and motor are rewound, the motor adjusted for medium speed, and the procedure repeated. Following this, the motor is again rewound, and the cylinder rotated at high speed, while photographs are taken just as before.

The child and crib are again pulled out into the room. The gears of the motor just used are placed in neutral, and the apparatus is adjusted for producing and recording the responses to the fast speed of oscillation of the cylinder, first with the single bar uppermost, and then with the group of 10 bars uppermost. After the latter procedure is completed, the cylinder is turned so the single bar is uppermost, the appropriate recording light is turned on, and the behavior of the subject in response to the stationary apparatus is photographed.

SUBJECTS

The subjects²² used in the main portion of the investigation are infants born at The Connecticut State Farm for Women, Niantic, Connecticut, between January 8th, 1929, and February 23rd, 1929, and all

²²Six regular subjects were used throughout the investigation. A seventh subject, Stanley P., had an infected eyelid at birth. He responded to the experimental situation satisfactorily, but was more sensitive to light than the other subjects, and only partially opened his eyes in the experimental situation. As a result, photographs of this child do not show eye-movements very satisfactorily, and after the second week, he was no longer used as a subject.

but a few of the subjects used in preliminary and supplementary investigations are infants being cared for in the nursery of the same institution. All the subjects are illegitimate children, and very little is known concerning their fathers.

Table 3 summarizes certain data having an important bearing on the developmental status²³ and health of the subjects.

The births of all the subjects are normal, but Wm. N. shows marked head-molding, and Dorothy R. has slightly granulated eyelids at birth. Harold C. is slightly premature ($8\frac{1}{2}$ months term), and labor is long and difficult, with marked head-molding. The estimate of prematurity²⁴ is based on the absence of finger and toe nails at birth, and on the large size of the anterior fontanelle. Raymond C. is also slightly premature—a term of 8 months is estimated on the basis of the following observations: lack of finger and toe nails, presence of some “lanugo” on the face and forehead, large anterior fontanelle, and early and pronounced “icterus neonatorum.” There is considerable head-molding, and the Wasserman is 4 plus, but the child shows no clinical signs of syphilis.

The health of the subjects is consistently good.

²³The writer is indebted to Dr. Ruth W. Washburn and Dr. Marion C. Putnam of the staff of the Yale Psycho-Clinic, for giving developmental examinations to the subjects. The examiners have had no previous contact with the infants, and are not allowed any information concerning the intelligence of the infants' mothers, or the experimenter's estimate of the relative ability of the infants, until after they make the estimates given above.

²⁴We are indebted to Dr. R. A. Jameson, the obstetrician in charge of the subjects, for the estimates of prematurity given above.

TABLE 3
SUMMARY OF MISCELLANEOUS DATA CONCERNING THE SUBJECTS

Name of subject	I.Q. of mother	Highest school grade attended by mother	Developmental quotient of subject	Weight at birth lbs.	Weight at six weeks lbs.	Gain in weight lbs.	Temperatures over 99.5° or under 98°	Temperatures over 98.5° on day of experiment
Dorothy R.	50	6	70? 60-70 or 70-80?	6	8	2	1	0
Harold C.	73	8	average	6	8	2	8	0
Anna M.	52	4	below 80 (borderline)	6	8	2	3	1
William N.	69	7	below average	7	10	3	1	3
Carolyn A.	98	9	average or above	7	10	3	9	3
Raymond C	70	7	average	7	7	0	6	4
Average	68.6	6.8		6	9	2	4½	2

Daily records of temperature show *no subjects with rectal temperatures over 100 degrees*, at any time during the investigation, and only two with temperatures over 99.5 degrees on days when photographs are taken (both 99.8 degrees).

Raymond C. loses 8 oz. during the first two weeks, and Anna M. loses 9 oz. the first week, but *no other subject loses weight during any week of the investigation*, and the average gain in weight per subject during the six week experimental period is 2 lbs., 4 1-3 oz.

Harold C. develops "snuffles" at two weeks, but the only other symptoms of illness are slight "colds," and *our experimental program is practically free from interruptions and postponements due to illness of the subjects.*²⁵

The experimental procedure is advanced or postponed one day in a number of instances, for various reasons, but the only deviations from schedule greater than one day occur in the two instances mentioned in note 25; and in case of Harold C., when a small portion of the procedure scheduled for the 35th day is not successfully completed until the 38th day on account of the unfavorable behavior of the subject.

Affective Behavior in the Experimental Situation.

²⁵Raymond C. has a slight cold at the end of the first week, which prevents the use of the medium speed of oscillation of the cylinder with the 10 bars uppermost, and the use of the fast speed of oscillation with both one bar uppermost and 10 bars uppermost. This gap in our data is not a serious one, since none of our subjects is able to adapt successfully to these situations at this age. Carolyn A. has a slight cold during the second week, which causes the postponement of the experimentation usually scheduled for the 13th and 14th days until the 15th and 16th days. There is no other interference with the experimental program on account of illness.

In order to protect the subjects from any possible injury from over-stimulation *leading to strongly emotional responses*, and in order to insure that the experimental data secured is not affected by the emotional condition of the child, the experimental periods are made short (see Table 2), and during each experimental period the affective behavior of the infant is recorded.

Table 4 summarizes briefly the above mentioned data for all experimental periods during which photographs are taken.²⁶ The affective behavior is indicated by symbols as follows:

S—satisfactory—a favorable response.

D—drowsy or sleepy—as shown by eye-shutting, yawning, etc.

F—fussing or fretting.

C—crying.

H?—hungry?—used when child fusses and cries while sucking hand, especially if it is close to feeding time. (If the fussing is stopped by feeding, or by giving a bottle of warm water, the interrogation point is omitted, and the symbol *H* is used alone.)

Small letters indicate a milder form of the same response, and two letters together indicate that the two responses occur simultaneously or alternately.

The first column represents the behavior of the sub-

²⁶Of course there are numerous instances when the subject is brought into the experimental room when his affective behavior is not favorable and no experimentation is attempted. Such instances are not given in the table.

ject at the beginning, the second column during the mid-portion, and the third column near the end, of the experimental period.

If we group all the favorable responses (all the *Ss*) in Table 4 together, and all the unfavorable responses, *F*, *C*, *D*, *H*, and divide the mixed responses equally between the two groups, we find that during the first 15 days 68.4% of the responses are favorable, and that from the 16th through the 42nd day 83.3% of the responses are favorable. We also find that 13 unfavorable responses occur in the third portion of the experimental period, and only 14 in the first two portions taken together. These facts suggest that fatigue, hunger, and sleepiness may be important factors which tend to make the third portion of the experimental period less favorable; and that these same factors are probably also at work in producing a larger proportion of unfavorable responses during the first 15 days than occur later.

It seems probable that these differences would be much greater if longer periods of experimentation were used, and that they might be lessened somewhat by using still shorter experimental periods.

In general the *affective behavior in the experimental situation is very favorable*. After the 14th day, the subjects only cry occasionally, and when they do it is usually possible to discover some definite cause, such as hunger or fatigue, which is extraneous to the experimental set-up.

In quite a number of instances a child who fusses before the experiment starts becomes quiet when the ap-

TABLE 4
AFFECTIVE BEHAVIOR IN THE EXPERIMENTAL SITUATION

Age of subject in days	Dorothy R.	Harold C.	Anna M.	William N.	Carolyn A.	Raymond C.
0		D D D			C (H?) ^k	S S SD
1					C	
2					C	
3				S S D	S S	
4			{ S S S sD sD sD			
5						
6		S SD SD				
7		S S S	S S S	S S S		HC S SD
8						
9						
10			S S Sg			
11			S S Sf Sfh			
12		S S S	S S S			
13	Sd Sd Dc	SC C C				
14	S S dca	S S S	S S S Si	FC FC FC		S S SD
15	F FD FDC ^b		CS S S	S S f	S S FC ⁱ	
16	S S f				F FC ^m S	
18						
20						
21	Fs S Sc	S S S	S S S		S SD S	S S S
22				S S S		
27				S S S	S S S	
28				S S S	S S S	
29	S S S	FCS S S ^e	S S S	S S S	S S S	S S S
34						
35	S S S	S S FC ^f	S S S	S S S	S DF FC	S S S
36		S S S				
38						
41	S S S (f) ^d	S S S	S S S	S S S	S S S	FS FS FS ⁿ
42						

S—satisfactory—a favorable response; D—drowsy or sleepy, as shown by eye-shutting, yawning, etc.; F—fussing or fretting; C—crying; H?—hungry? Small letters indicated a milder form of the same response; and two letters together indicate that the two responses occur simultaneously or alternately. For notes see p. 371.

paratus begins to move, and thenceforth responds very favorably to the situation.

METHOD OF STUDYING THE CINEMA RECORDS

The first plan for studying the film is to plot the movements of the head and eyes, frame by frame, using a projector with a lens having a focal length of three inches. By means of this arrangement eight frames are simultaneously projected on a long and narrow translucent screen, 31 inches high and 9 inches wide, at approximately life size. This screen is movable horizontally and carries a vertical line which is adjusted so as to be exactly parallel to the edge of the film. When this line passes through a certain point in one

^aCried just before end of experimentation. Total time in experimental room, 10 minutes.

^bChild awakened by nurse. Some other experiments are tried before photographs are taken; 20 minutes is spent in experimental room but condition of the child is not favorable for experimentation and only 10 feet of film is used.

^cStopped fussing when given warm water.

^dChild quiet during regular experimentation. At end of usual procedure the drum is rotated continuously for several minutes, after which the subject becomes fussy; 15 minutes in experimental room; 15 minutes before feeding time when experiment is discontinued.

^eChild fusses at beginning. Quiets when given bottle of warm water.

^fExperiment takes longer than usual, because film has to be changed. Child fusses near end; 20 minutes in experimental room.

^gSlight fussing between experiments, but not during them.

^hSlight fussing (it is feeding time).

ⁱCries once at the beginning, and then quiets.

^jFusses while in experimental room, after all the film in the camera has been used up (47 feet used); 15 minutes in experimental room.

^kStops crying while the apparatus is moving.

^lTired? (long session—66 feet of film used); 15 minutes in experimental room.

^mExperiment commences just before feeding time. Affective response satisfactory after feeding.

ⁿCries between experiments but not during them. Hungry? Had been placed on a bottle a few days previously; 20 minutes in experimental room.

frame, the relative horizontal movement of this point in the other frames can be easily seen. An extension of the frame of the translucent screen carries a piece of heavy transparent celluloid, which is pierced by a vertical row of holes made with a No. 72 drill. The position of a point in one frame is plotted by placing the vertical line on the point, and then pressing a sharp stylus through the first of a row of holes, and through a sheet of paper fastened to a board by means of thumb-tacks. The apparatus is then adjusted to the same point in the next frame, the stylus is pressed into the paper through the second hole, and so on, thus securing a graphic representation of the horizontal movements in terms of the position of the successive perforations in the paper.

The procedure just outlined is a satisfactory, although laborious, method for plotting horizontal head-movements or for plotting eye-movements when the head is stationary, and offers certain advantages over methods of plotting which only allow one frame to be seen at a time. Unfortunately, however, the children move their heads almost continuously when their eyes are open; and the excursions of the head-movements are so much greater than those of the eye-movements that the completed graphs do not form clear records of the latter and cannot be interpreted with certainty.

By repeated direct observation of the moving pictures projected from a few feet of film at a time, it is possible to determine satisfactorily the grosser aspects of the eye-movements observed. The following convenient arrangement is used for making the observations. By means of a properly placed mirror, a slightly

greater than life-size image formed by a hand-driven moving picture projector is focused on a finely ground glass screen ²⁷ placed from 15 to 18 inches in front of the eyes and at an angle and height which allow the observer a comfortable posture while cranking the projector and making observations.

Saccadic eye-movements in the direction opposite to that of the stimulus are easily observed and can be checked conclusively by going over the film again frame by frame. These movements usually occur during one frame (i.e., in less than 1-16 of a second), and the difference in position of the eye from one frame to the next is obvious (see Figure 5); but occasionally what appears to be a similar movement is spread over two frames. Coordinate compensatory eye-movements can be satisfactorily checked by repeated observation of the film. Finally, the saccadic adjustments, for the most part in the direction of pursuit, which make up "pursuit" eye-movements, can be counted, although unquestionably many fine adjustments are missed, and pursuit described as "smooth" is probably broken by tiny adjustments such as show in highly magnified eye-movement records secured by the corneal reflection method. The task of counting saccadic adjustments is made more difficult when the head-movements are rapid.

Although the limitations of the method of studying films adopted in the present investigation are freely admitted, the method is adequate for determining the grosser characteristics of optic nystagmus and ocular pursuit movements in young infants.

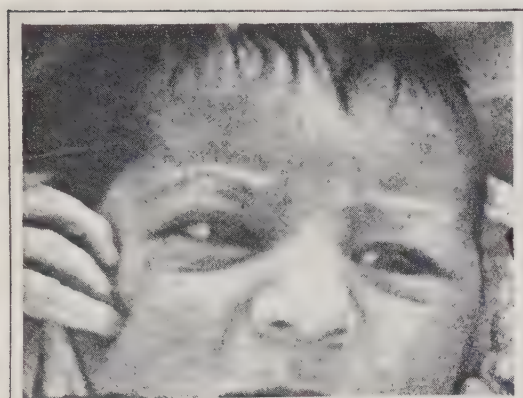
²⁷The best grade of ground glass furnished by the Eastman Kodak Co.

III RESULTS

THE FIRST OCCURRENCE OF OPTIC NYSTAGMUS

Optic nystagmus *always* occurs when the subject holds his eyes open in our experimental situation during the rotation of the cylinder at slow speed or at medium speed, i.e., at the rate of one revolution in 36 seconds, or in 18 seconds, respectively. The consistency of occurrence of optic nystagmus in our experimental situation, as contrasted with the inconsistency of the response produced when a kymograph drum covered with white paper carrying longitudinal black stripes is rotated slowly in front of an infant's eyes (the procedure used in our preliminary experiments and by investigators mentioned above), is not surprising. In our experiments the problem of keeping the eyes of the infant directed on the moving barred field is eliminated by the form of the apparatus, but if the small kymograph drum is used, the infant may respond to it, or to any other object which happens to be in the field of vision.

All of our subjects respond with a lively optic nystagmus the first time they hold their eyes open in the experimental situation. Dorothy R. first opens her eyes in the experimental situation on the 13th day, and a definite nystagmus is observed and photographed at both slow and medium speeds. Stanley P. is first successfully photographed with his eyes open on the 7th day. A very definite optic nystagmus occurs at both slow and medium speeds.



A
Carolyn A, age 35
hours



B
Carolyn A, age 2
days and 10 hours



C
Anna M, age 3
days and 20 hours

FIGURE 5
VERY YOUNG SUBJECTS RESPONDING TO THE APPARATUS

Anna M. at the age of 3 days, 19½ hours, responds with a definite optic nystagmus to both the slow and medium speeds of rotation of the cylinder. William N., 58 hours after birth, reacts to the slowly moved cylinder with a lively and well-sustained nystagmus. His response to the medium speed of rotation of the cylinder is a nystagmus consisting of pursuit movements, broken by three saccadic eye-movements in the direction opposed to the direction of the movement of the apparatus. These eye-movements in the direction opposite the movement of the apparatus are henceforth referred to as refixations. (The term is not entirely satisfactory, but is adopted for convenience.) All of these occur while the barred field is passing the camera. Carolyn A., at 11½ hours, does not keep her eyes open continuously during an entire slow revolution of the cylinder, but the records show two separate periods of lively nystagmus, in response to the movements of the groups of bars on the cylinder surface, during two separate revolutions. One contains 5 refixations and the other contains 10.

Harold C. is available for experimentation at the age of 75 minutes.²⁸ He does not open his eyes in the

²⁸Dr. Jameson, during this investigation, makes the observation that infants remain awake, with their eyes open a large part of the time, for an hour or more immediately after birth. This period is particularly favorable for studying the ocular responses of the infant, as long as only a moderate illumination is used. Once the infant is asleep, and especially after the first feeding, it is very difficult to rouse him sufficiently for satisfactory experimentation. This is a serious difficulty in attempting experiments during the first two weeks.

Since there are no sleeping accommodations on the grounds for *E.*, he is not available at night, when most of the infants are born, and in most cases it is impossible to experiment on them immediately after birth.

brightly illuminated experimental situation, but when the illumination is reduced by turning off the photographic lights, he reacts to the slowly rotating drum with a typical optic nystagmus.²⁹ The eyes close from time to time, and the optic nystagmus is not very well sustained. The experiment is repeated several times, with the same result.

It is first possible to secure photographs of optic nystagmus in this child at 5 days, 16¾ hours. At slow speed 7 refixations are observed during what is approximately one-half of a revolution, beginning just before the single bar, and ending when the eyes are shut in the neighborhood of Bar 4. Pursuit movements, varying in extent, occur between the refixations.

The film shows that during a wink the lids close during one frame, and remain closed for two frames, and while the lids are closed the eye makes a saccadic movement in the direction opposite the movement of the drum. This movement is rapid, occurring in less than 2 frames (approximately 1-8 second). The occurrence of saccadic jerks in the direction opposite the direction of pursuit during winks is frequently observed later in this same subject, and also in others.

The response of Harold C. to the medium speed of rotation, following immediately after the slow rotation, is very unsatisfactory, because the eyes are closed most of the time. The head is moved slightly in the direction of movement of the striped field, and two slow pursuit movements occur in this same direction, but saccadic movements in the opposite direction are completely

²⁹Dr. Jameson, who was present, corroborates this observation.

lacking. On the following day, during the most rapid speed of the drum, three refixations occur. One occurs in the neighborhood of Bar 11, one close to Bar 1, and one between Bar 7 and Bar 8. The lid behavior is again interesting here. The lids are shut momentarily (5 to 10 frames) four times during the revolution of the drum. This phenomenon occurs three times during the passage of the barred half of the visual field, and only once during the other half, and then in the vicinity of Bar 11.

Finally, Raymond C., a premature, exhibits a good optic nystagmus, 11 and $\frac{3}{4}$ hours after birth. This child is so sensitive to light that he does not open his eyes in the illuminated experimental situation. The lights are therefore turned off, and the crib pulled partially out of the cylinder, so that the child's face is dimly illuminated by the light from the room. Photographs are taken under these circumstances, but they are badly under-exposed and contain only partial records of the movements of the rotating cylinder. However, this film, when projected on a "day-light" screen in a dark room, does show a definite optic nystagmus and furnishes objective evidence of the correctness of the observations made at the time.

Since all seven of our subjects show optic nystagmus when first experimented upon, since three of them, including one premature, are tested during the first 12 hours after birth, and since one subject is tested at the age of one hour and 15 minutes, we have very strong evidence that this response is based on a neural mechanism which is ready to function at birth, even in slightly premature infants.

Our results agree with an observation by Bárány, as opposed to Bartels, who is unable to observe optic nystagmus in infants during the first day (see page 329).

THE FIRST OCCURRENCE OF PURSUIT, SACCADIC, AND COORDINATE COMPENSATORY EYE-MOVEMENTS

Since the slow phase of optic nystagmus is usually (107, p. 91; 122) considered to be identical with the pursuit movements of the eyes (Dodge's Type II), and since the quick phase of optic nystagmus is usually considered to be identical with the saccadic eye-movement (Dodge's Type I), we are able to conclude from the data on first occurrence of optic nystagmus that the ability to make these two types of ocular movements is present from birth.

The records of the eye-movements in response to the oscillatory movements of the drum also show both pursuit movements and saccadic movements in the opposite direction during our experiments at the earliest ages.

The determination of the time of the first occurrence of coordinate compensatory eye-movements proves to be a more difficult problem than the determination of the first occurrence of saccadic and pursuit movements. Coordinate compensatory eye-movements occur much less frequently during our experiments than do pursuit movements and saccadic movements. The total number of occurrences of these movements during the first six weeks of life is very small, and therefore any conclusions drawn from our data must be limited. A coordinate compensatory eye-movement is observed during the second period of experimentation on Dorothy R. when 14 days of age. Other occurrences of this

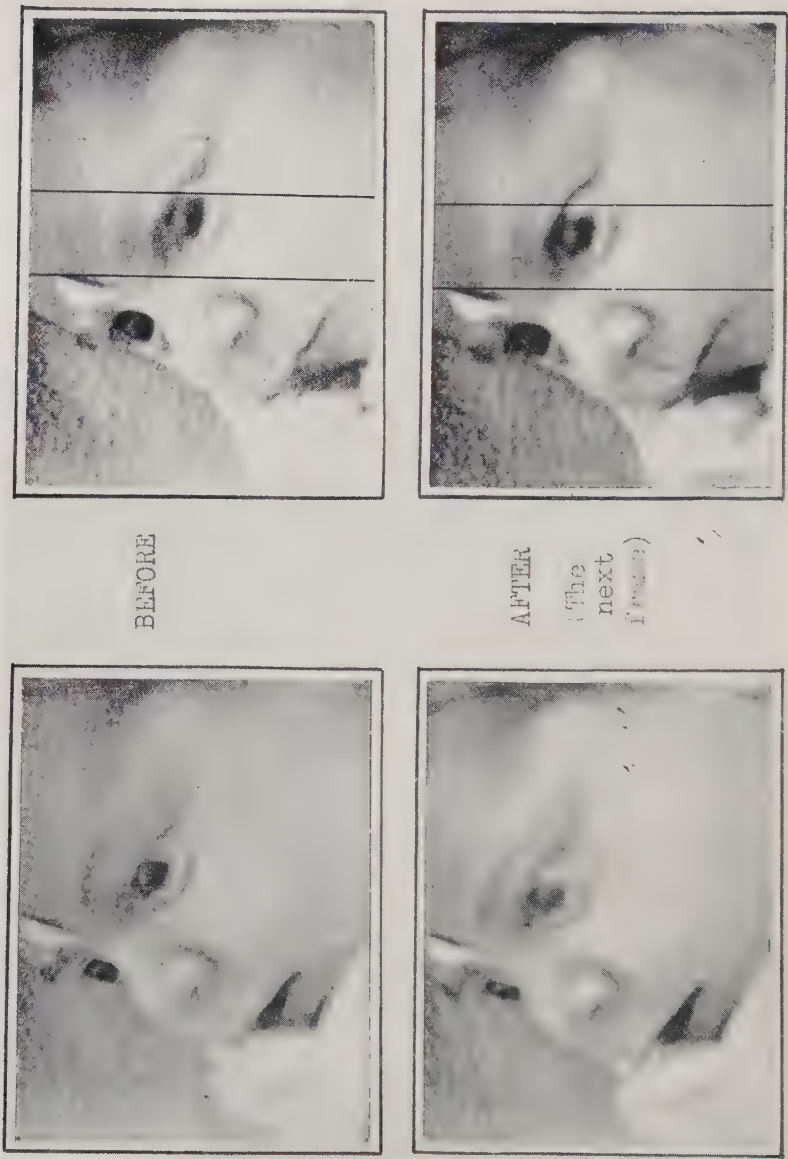


FIGURE 6
SACCADIC EYE-MOVEMENTS

movement are observed in case of this child at 20 and at 21 days. Stanley P. exhibits a coordinate compensatory eye-movement on the 7th day and again on the 8th day. Harold C. exhibits a somewhat doubtful eye-movement of this type on the 6th day, but does not do so again until the 36th day. However, on and after the latter date this child shows a larger number of such eye-movements. Anna M. makes three coordinate compensatory eye-movements during her first experience in the experimental situation when 3 days and 19 hours old. William N. does not make any eye-movements of this type until the 15th day, but several occur during the experimentation on that day. Carolyn A. makes a coordinate compensatory eye-movement at the age of 35 hours but not again until the 21st day. Raymond C. does not exhibit any such eye-movements until the fourth week. It is possible that the fact that this child is about 4 weeks premature may be a factor in the absence of these eye-movements. It may possibly indicate that the neural basis for this response does not mature until near the time of birth.³⁰ On the other hand, factors other than the development of the control of the ocular muscles may be of fundamental importance in the development of this particular type of eye-movements. A newborn infant, and particularly a premature infant, has relatively little strength in his neck muscles, and as a result does not move his head very often, and as long as there are no head-movements,

³⁰See Tilney and Casamajor (143) for an interesting experimental study of the relation between myelinization in the nervous system and maturation of behavior patterns in kittens.

there is no occasion for the occurrence of coordinate compensatory eye-movements. Also, it is entirely possible that this child is able to make such eye-movements from the time of birth or shortly after but that he does not happen to exhibit this ability in the experimental situation.

The time of first occurrence of coordinate compensatory eye-movements is seen to be quite variable. However, as only a few of these movements occur, a large variation is to be expected and does not necessarily indicate a real difference in the behavior patterns of the children studied. It is quite possible that the ability is present earlier in children where it has not been observed. The only definite conclusion that we can draw concerning the first occurrence of this response is that *coordinate compensatory eye-movements do occur within a few days of birth*. However, it is possible that the ability to make eye-movements of this type is present from the time of birth, even though they do not occur during the limited number of experiments with infants on the first day.

Coordinate compensatory eye-movements play a much smaller part in the oculo-motor responses of an infant during the first six weeks of life than they do a few months later. It seems probable that this difference is due, at least in part, to the much greater amount of bodily activity shown by the older children, since there is no occasion for this type of eye-movements when the head and body are held motionless.

During the preliminary experiments dealing with the ability of an infant to look from one spot of light to another, when the latter appears successively on a rela-

tively uniform background, several subjects³¹ approximately six months of age are used. Coordinate compensatory eye-movements play a prominent part in the responses of infants at this age. A six-months-old infant is very active when placed in the dorsal position on a flat, padded surface. He not only moves his head from side to side, and his body as well, but he is also able to keep his eyes directed quite consistently toward a spot of light, for short periods, during the movements of the head and body in any direction. He does this by means of numerous coordinate compensatory eye-movements. No behavior similar to this is observed in experiments during the first 12 weeks.

These few observations of coordinate compensatory eye-movements at various ages indicate that a study of the number of such eye-movements occurring under identical experimental conditions, in infants during the first few weeks of life, and in infants about six months old, would show pronounced age differences. However, the data are too limited to permit definite conclusions.

THE CORRESPONDENCE BETWEEN EYE-MOVEMENTS DURING OPTIC NYSTAGMUS AND THE POSITION OF THE BARS IN THE MOVING VISUAL FIELD

The determination of the exact relationship between the objects moving in the visual field during optic nystagmus and the eye-movements occurring is of fundamental importance in connection with the theory of

³¹Provided for by the Yale Psycho-Clinic and the Children's Community Center of New Haven.

production of optic nystagmus and is of particular interest in connection with the occurrence of this response in early infancy.

The accurate determination of this relationship is very difficult since it is necessary to know both the position of the bars on the cylinder and the direction in which the head and eyes are directed. This determination becomes especially difficult when the head is not fixed in position, as is the case in working with infants.

Moving picture records, when combined with a device for recording the passage of the individual bars in front of the camera, offer an advantage over any other known recording technique for the solution of this problem with infant subjects. The advantage is that such pictures enable the person studying the film to estimate the approximate direction in which the child is looking. When the child is looking directly at the camera, one can make this estimate with considerable confidence;³² when the subject is looking to the side at an angle of from 45 to 90 degrees, this cannot be done so satisfactorily. However, even in this case it enables one to make a better estimate as to where on the film the responses to the group of bars, or to the single bar, should come. If we find, in the moving picture records, refixations which follow approximately the rhythm of the passage of the bars in front of the camera, and if we find that the discrepancy between the rhythm of the

³²Preliminary experiments with 4 adults indicate that an observer can estimate the direction of regard with surprising accuracy (usually within less than 5 degrees) when the subject is looking at or near the observer, and less accurately when looking further away from him.

passage of the bars and the rhythm of the refixation agrees approximately with the differences to be expected from our estimate of the position of the child's regard with respect to the camera, then we can estimate the degree of correspondence between the stimulating situation and the response with more certainty than would be the case were the relation of the direction of regard with respect to the position of the camera entirely unknown.

We have two types of evidence showing whether or not there is any relationship between the passage of the bars in the visual field and the movements of refixation.

1) The most direct evidence consists of the complete and accurate analysis of the head- and eye-movements occurring during an entire revolution of the drum, combined with the record of the passage of the bars. When the head is directed at the camera at the beginning of the experiment, and remains practically motionless, this evidence is particularly certain and conclusive. Unfortunately, this favorable circumstance occurs only part of the time.

Detailed description of the response when the head is not directed toward the camera at the beginning, or when the head is moved a great deal, is valuable, but less so than when the head position is favorable and the orientation of the head relatively constant.

A highly accurate study of the correspondence between the individual saccadic eye-movements and the passage of the bars in the visual field is possible only when the child is looking in the direction of the camera, or at least near it. If the child is looking to the left of the camera, part of the responses to the group of

bars should be expected to occur at the beginning of the revolution and part at the end. If, on the other hand, the child is looking to the other side of the camera, the response to the single bar should be expected to occur sooner than would otherwise be the case, and the movements in response to the group of 10 bars should all occur together. In case the child changes the direction of his regard in a radical manner during the revolution of the cylinder the determination of the relation between the passage of the bars and the response to them is made more complicated. This relation can be determined approximately by making subjective estimates of the direction of the child's regard from time to time during the rotation of the cylinder. This procedure is probably of value, but it contains sources of error which cannot be accurately evaluated. As a result, we base our conclusions concerning the exact relationship between the refixations and the bars in the visual field only on those records in which the head faces the camera or very close to the camera, and in which the head-movements are relatively small in extent.

The earliest completely satisfactory record of a child's response to a complete revolution of the rotating cylinder is that of William N., aged 58 hours, in response to the slow speed of the apparatus. At the beginning of this response the child's eyes are directed slightly to the left of the camera. A refixation occurs very soon after the camera is started, another occurs in the region of the single bar, a third occurs between the single bar and Bar 1, and nine refixations occur during the passage of the group of 10 bars. This re-

sponse shows an almost perfect correspondence between the refixations and the bars except that one additional refixation occurs between the single bar and the beginning of the group of bars. During the medium speed of rotation of the cylinder (which occurs within a minute of the experiment just described) this child shuts his eyes most of the time and only three refixations occur during the group of 10 bars.

Anna M. when 3 days and 19 hours old responds to the slowly rotating cylinder with a definite optic nystagmus. At the beginning of the photographs the child is looking about 15 degrees to the right of the camera and the eyes are partly closed. First they open slightly, then they open completely, and move in the direction of the moving cylinder. There is a pause, another pursuit movement to the left, a refixation to the right, pursuit left, refixation, a coordinate compensatory eye-movement with the head moving right and the eyes left, and then a refixation to the right just as the single bar passes the camera. Following this there is a refixation, two pursuit movements left, a head-movement left with a coordinate compensatory eye-movement to the right, two pursuit adjustments to the left, a saccadic movement right, two refixations to the right, and two pursuit movements to the left. Following the passing of the first bar two pursuit adjustments to the left occur, then there is a very small eye-movement to the right, following which the eyes are held practically motionless but directed far to the left until the seventh bar passes the camera. A refixation to the right occurs here and no more eye-movements occur during this revolution of the cylinder. A total of 8 refixations

occur, and it is difficult to determine accurately the correspondence between the refixations and the movements of the individual bars, but the correspondence appears to be only approximate.

The following is a description of the response of Harold C., when 13 days of age, to the medium speed of rotation of the drum. At the beginning the child is faced about 30 degrees to the left of the camera. At the very start there are five saccadic eye-movements to the right, then the head is moved far to the left and the head and eyes remain stationary for several seconds. Then in the region of the single bar there is a *long* pursuit to the left and a single refixation. Five more refixations occur during the group of bars.

Since the child is facing to the left of the camera at the beginning, a number of bars pass the child's eyes before the passage of the single bar is recorded on the film, and the single bar does not come in front of the infant's eyes until some time after it passes the camera. Also, while the 10 bars are passing the camera, only part of them pass in front of the infant. When we take these facts into consideration, the correspondence between the occurrence of the refixations during the response just described and the movement of the bars in the visual field is practically perfect.

The responses of Dorothy R. at 21 days make good material for a detailed analysis with respect to the correspondence between refixations and the bars on the cylinder. At slow speed, a total of 13 refixations occur. The response begins with a long pursuit, involving five pursuit adjustments, and two comparatively small head-movements in the same direction, then the

eyes are shut momentarily, following which there are four saccadic adjustments and a head-movement to the right. These eye-movements just mentioned are close together, and a comparison with the stimulus record indicates that the long pursuit was directed at Bar 10, and that the four eye-movements and the head-movement in the opposite direction served to direct the eyes on the single bar. Next there is a pursuit movement of rather small extent, but lasting nearly a second, followed by four more saccadic movements to the right. These appear to direct the eyes toward Bar 1. Then there is again a long pursuit composed of four adjustments, occurring at the same time that pursuit movements of the head occur. The eyes shut momentarily, and another pursuit adjustment occurs immediately after they are opened. From this point on there is a slow ocular pursuit, broken by five refixations. The rhythm of these refixations corresponds almost exactly with the passage of the individual bars. It is obvious that the correspondence between the refixations and the passage of the bars is not perfect, but certainly near the end of the revolution of the cylinder there is a one to one relationship between the passage of the bars and the occurrence of refixations.

It is also noteworthy that the pursuit movements which correspond to the last of the group of bars, and which correspond to the bar placed alone, result in a greater displacement of the head and eyes than occurs during the rhythmic responses to bars within the group. (This is typical of many of the records.)

The responses of this same child to the next situation (the medium speed of rotation of the cylinder) again

merit detailed discussion. At the beginning she is looking slightly to the left of the camera, which is started as Bar 10 passes it. Pursuit movements occur immediately, but are broken by two refixations in quick succession. Then a long period (approximately $4\frac{1}{2}$ seconds), during which there are no definite eye-movements, is followed by a saccadic movement to the right. In turn, this is followed by a pursuit composed of very fine adjustments, which lasts about 4 seconds, and is succeeded by four refixations, which are separated by pursuit movements.

In the response just described, two refixations corresponding to the last of the group of bars, a definite response to the single bar, consisting of a saccadic movement opposite the direction of movement of the cylinder, and a pursuit of long duration, occur in succession and are followed by a series of refixations which correspond to the first portion of the group of bars. In this case we cannot expect an exact correspondence between the total number of refixations and the number of bars on the cylinder surface, because, even though the cylinder makes a complete revolution, the subject's head deviates somewhat to the left, with the result that not quite all of the barred field passes in front of her eyes.

We choose the responses just described, which are typical examples of the optic nystagmus occurring in the responses of the subjects to the rotating cylinder, for detailed description here only because the records of these responses are particularly favorable for study. A comparison between the examples described above and Table 5, which gives the number of refixations

occurring per revolution of the cylinder, for each child, at each speed of the cylinder, during each of the first six post-natal weeks, indicates that the examples described above are truly representative of the groups of responses to which they belong.

We could describe many more responses in detail, but it is not advisable to do so. All the responses recorded have been analyzed, and in nearly all instances they show an approximate, although usually not perfect, correspondence between the occurrence of refixations and the position of the bars in the visual field when the cylinder is rotated at slow and medium speeds. However, at the rapid speed of rotation the number of refixations is much smaller than the number of bars on the cylinder lining, and at this speed, especially during the first three or four weeks, one refixation appears to correspond to a group of two or three bars, rather than to a single bar.

2) In those records in which it is impossible, on account of the position or the movements of the infant's head, to determine with certainty the exact degree of correspondence between the eye-movements and the positions of the individual bars in the visual field, we have a second method, which, although less direct, is nevertheless valuable. This second method is a statistical one. It is based on the assumption that if the relationship between refixations and the objects in the visual field, which is suggested by the study of the individual records, actually exists, the number of refixations occurring during one revolution of the cylinder should approximate 11—the number of bars on the surface of the cylinder.

TABLE 5
NUMBER OF REFIXATIONS PER REVOLUTION OF THE CYLINDER*

Time required for one revolution of cylinder.	Age in weeks	D.R. S.P. H.C. A.M. W.N. C.A. R.C.										Average		Number of revolutions	Average	Median	Mode	Range	S.D.	Cases falling on 10, 11, and 12	Percentage of cases falling on 10, 11, and 12	Number of revolutions	Average	Median	Mode	Range	S.D.	Cases falling on 10, 11, and 12	Percentage of cases falling on 10, 11, and 12	S.D.	Cases falling on 10, 11, and 12	Percentage of cases falling on 10, 11, and 12								
		1	2	3	4	5	6	7	8	9	10	11	12																				13	14	15	16	17	18	19	20
36 seconds	1	11	7	8	—	10	10	9.2	{		14	11.93	12.0	7-20	3.77	4	28.7	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57			
	2	7	4	13	7	20	14	13.2	5	15	—	13.25	{		18	8.83	10	12	2-13	1.91	7	38.9	{		18	3.66	3.75	2	0-8	2.0	0	0	36	4.81	4.86	4	0-11	2.49	1	2.8
	3	13	—	18	9	—	15	—	13.25	{		18	5.94	7	4 & 7	1-11	2.62	1	5.6	{		18	5.94	7	4 & 7	1-11	2.62	1	5.6	{		18	5.94	7	4 & 7	1-11	2.62	1	5.6	
18 seconds	1	11	0	3	3	5	6	8.0	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57		
	2	2	11	11	11	11	10	10.625	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57		
	3	7	10	11	11	11	12	10.2	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57		
9 seconds	4	8	13	8	12	13	12	11.0	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57		
	5	12	10	11	2	12	2	8.2	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57		
	6	9	2	6	11	9	7	7.33	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57		
3 seconds	1	2	3	3	2	4	2.8	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57			
	2	4	8	6	3	2	5.1	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57			
	3	2	0	4	2	3	2.7	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57			
6 seconds	4	6	8	5	8	7	4	6.3	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57		
	5	7	9	7	9	4	6.6	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57			
	6	5	1	1	11	4	4.8	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		17	10.00	11.03	11	6-12	1.82	13	76.4	{		35	9.40	10.9	11	2-13	1.90	20	57			

*Boldface numbers represent responses during which the eyes are not open during an entire revolution of the cylinder. These numbers are omitted in the calculations.

TABLE 6
AVERAGE NUMBER OF REFIXATIONS PER REVOLUTION OF THE
CYLINDER
(From the second through the fifth week)

Time per revolution (seconds)	Number of revolutions	Average	Median	Mode	Range	<i>S.D.</i>	Number of cases falling on 10, 11, and 12	Percentage of cases falling on 10, 11, and 12
18	26	10.04	11.33	12	2-13	2.78	18	69
9	25	5.25	5.50	4 and 7	0-9	2.38	0	0

While there are considerable variations in individual instances, Tables 5 and 6 clearly show the general tendency in the case of the slow, and a still greater tendency in the case of the medium speed of movement of the visual field, for the number of refixations during each revolution of the cylinder to approximate the number of bars on the cylinder surface. This tendency varies with both the speed of movement of the cylinder and the age of the child.

Although the data in Tables 5 and 6, when taken alone, are hardly conclusive proof that there is an approximate correspondence between the occurrence of refixations during a revolution of the cylinder and the position of bars on the surface of the cylinder, these data form an excellent statistical confirmation of the relationships discovered by detailed analysis of the best photographic records.

The averages, medians, and modes of the number of refixations occurring during one rotation of the cylin-

der at slow and medium speeds (see Table 5) not only approximate the number of bars on the cylinder surface, but also approximate very closely the number of refixations occurring in the records most favorable for detailed analysis. This correspondence between the measures of central tendency based on all the records and the individual figures based on the best records shows that the most favorable records are typical of all the records of the group with respect to the number of refixations occurring. It seems very probable that the best records, which are typical of the group in the number of refixations occurring, and which are taken under conditions similar to those under which the records for the rest of the group are taken, will also be typical of the group with respect to the distribution of the refixations, and with respect to the relation between refixations and the bars on the cylinder surface.

THE EFFECT OF THE SPEED OF ROTATION OF THE CYLINDER ON THE EYE-MOVEMENTS OCCURRING IN OPTIC NYSTAGMUS

The speed of rotation of the cylinder has a definite effect on the number (and probably also on the extent) of the refixations which make up the quick component of optic nystagmus. Table 5 shows clearly that the average number of refixations during each of the first three weeks is, without exception, greatest for the slowest speed, next for the medium speed, and least for the fastest speed of rotation of the visual field. During the fourth, fifth, and sixth weeks the average number of refixations per revolution of the cylinder is always

greater for the slower than for the faster of the two speeds used (see Figure 7). Of course, in individual cases there are deviations from this general rule.

Data given in Table 7 indicate that the differences between the average number of refixations at slow and at fast speeds and between the number at medium and fast speeds are highly reliable for the periods of weeks averaged in Tables 5 and 6; but the difference between the average number of refixations at slow and medium speeds during the first three weeks is somewhat less reliable.

After studying the moving picture records, we have a very definite impression that the extent of the saccadic movements referred to as refixations is also greater for the slower than for the faster speed, and that the extent of the movements of refixation at the most rapid speed increases somewhat with increasing age. But methods of analysis so far used do not give any objective data which confirm or refute the correctness of the impression.

THE EFFECT OF AGE ON OPTIC NYSTAGMUS

Although the optic nystagmus which occurs in the human infant almost immediately after birth is similar in its essential characteristics to the optic nystagmus of an adult subject, the responses of the infant change somewhat with increasing age.

On account of the small number of experiments at each age and the resulting inconsistencies in our data, it is difficult to conclude with certainty concerning the exact effect of age and practice on the number of refixations occurring during optic nystagmus. However,

TABLE 7
RELIABILITY OF THE DIFFERENCES BETWEEN THE AVERAGES IN
TABLES 5 AND 6

Measurements compared		Difference	$S.D.$	$\frac{Diff.}{S.D.}$	Chances in 100 of a true difference greater than zero
First three weeks	Slow and medium speeds	1.93	1.10	1.7	96
	Slow and fast speeds	8.27	1.11	7.5	100
	Medium and fast speeds	6.34	.65	9.8	100
Second three weeks	Medium and fast speeds	3.67	1.53	2.4	99.2
All six weeks	Medium and fast speeds	5.13	.69	7.4	100
From the second through the fifth week	Medium and fast speeds	5.52	.65	8.5	100
Medium speed	First three and second three weeks	.39	1.09	.4	62
Fast speed	First three and second three weeks	2.28	.79	2.9	99.8

the last two rows in Table 7 indicate that, in case of the medium speed, the difference in the average number of refixations per revolution of the cylinder, for the first three weeks as compared with the second three weeks, is small and unreliable; but at the fast speed the corresponding difference is larger, and is reliable. These data are interpreted to mean that during the first six weeks age exerts a more marked influence on the characteristics of optic nystagmus occurring in response to rapid rotation of the apparatus than on optic nystagmus occurring in response to slower revolutions of the apparatus.

Figure 7 shows the smoothed curves based on the average number of refixations occurring per revolution of the cylinder, during each week. The small number of cases involved causes any statement as to the reliability of the differences between the weekly averages to be of doubtful validity. However, at slow speed the differences between the average for the first and second and for the first and third weeks are much more reliable than are the differences between the averages at the second and third weeks.

Again, at medium and fast speeds, the differences between the average for the first week and the averages for the fourth and fifth week appear to be quite reliable. Also, the differences between the average for the sixth week and the averages for the fourth and fifth weeks are fairly reliable, whereas the differences between the averages for the third, fourth, and fifth weeks are of lower reliability. These facts concerning the reliability of the differences between various points on the graph, along with the similarity in the general

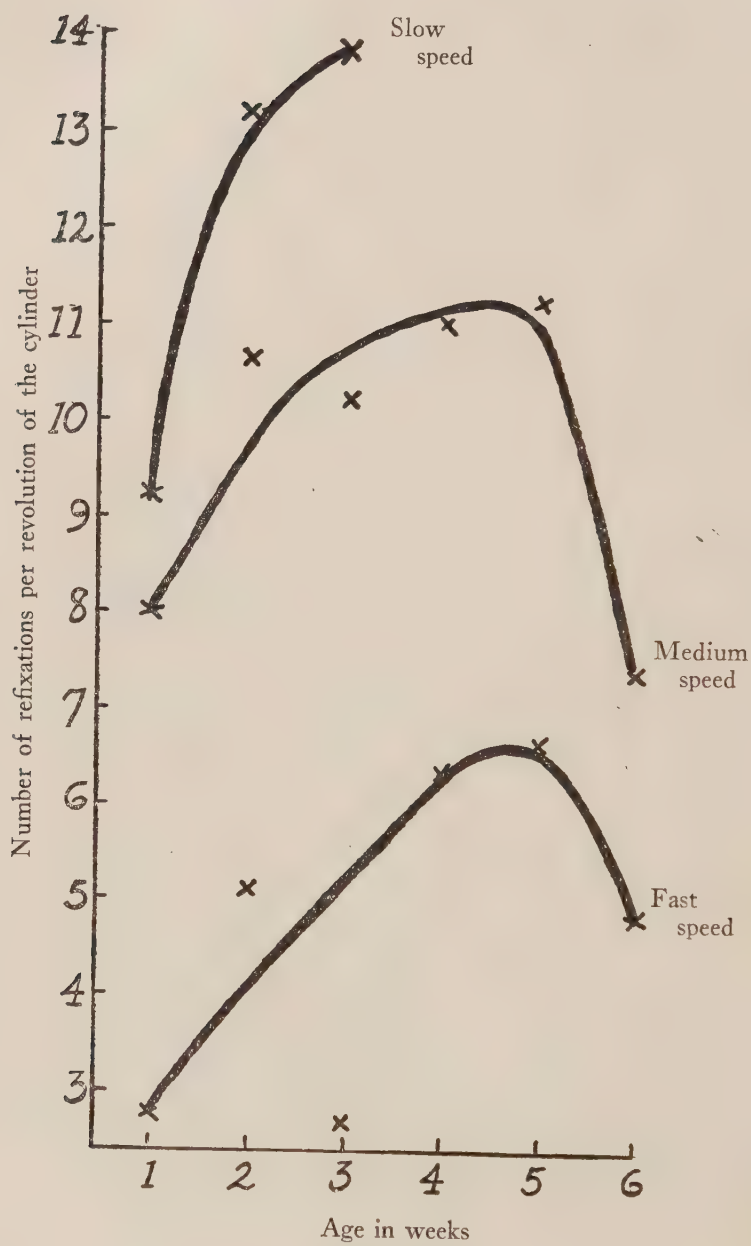


FIGURE 7

shape of the various curves, lend support to the following interpretation, which is suggested by Figure 7 and by study of the actual responses made by the subjects. The interpretation is that there is a gradual increase in the average number of saccadic eye-movements opposite the direction of movement of the cylinder until a certain maximum is reached. In case of the medium speed this maximum average corresponds very closely to the number of bars on the cylinder surface; and in case of the fast speed it corresponds somewhat less closely to one refixation for the single bar, and one refixation for every two bars on the opposite side of the cylinder, i.e., a total of 6.

After the maximum is reached there is a dropping off of the averages in case of both medium and fast speeds.

The reduction in the average number of refixations during the sixth week, as opposed to the fifth, is not a chance variation due to the small number of cases on which the averages are based, but is due to a qualitative difference in the responses made by certain subjects. For example, during the sixth week, instead of holding their heads relatively still, and reacting with an optic nystagmus, two of the infants (Harold C. and Anna M.) follow the movement of the cylinder surface through an angular distance of almost 90 degrees by means of a head-movement before they jerk the head quickly back to the original position, or even beyond, and again pursue a portion of the visual field for a long distance.

The use of the head in this manner appears to be an additional development in the child's ability to orient

himself in visual space. The pursuit movements which compose the slow phase of optic nystagmus are the eye-movements which permit clear visual perception in case of the adult, and it seems safe to assume that pursuit movements have the same function for the child as for the adult. By means of optic nystagmus the infant is able from the very first to direct his eyes for a short time toward one portion of the moving visual field, and then toward another. However, optic nystagmus only allows the eyes to be directed toward a certain portion of the moving visual environment for a relatively short period. The head-movements described above enable the child to follow one portion of the cylinder surface through an angular distance of over 90 degrees, and therefore give a longer opportunity for the visual perception of a particular portion of the moving cylinder surface than is permitted by optic nystagmus.

OPTIC NYSTAGMUS DURING SLEEP

Certain writers believe that optic nystagmus is involuntary and that the cortex is not involved. Coppez (114, pp. 125-126) believes that it is non-conscious and that the cortex is not involved. Wirths (141, pp. 334-345) believes that the slow phase is purely reflexive and cannot be suppressed during the correct research procedure. Bartels (103) believes that this response is mediated by a neural path which does not involve the cortex and that attention is not necessary for the production of optic nystagmus; and Wilbrand and Sanger (140, Vol. 8, p. 22) maintain that it is possible that the mechanisms of production of the quick phase of optic and of vestibular nystagmus are identical.

If it is true that either or both phases of optic nystagmus are mediated by a mid-brain reflex, without any necessary participation of cortical paths, conditions which interfere with the activities of the cortex should not interfere with optic nystagmus, and optic nystagmus should occur under conditions which permit the occurrence of the pupillary light reflex, and the slow phase of vestibular nystagmus, both of which are generally considered to be mid-brain reflexes. It is known that the pupillary light reflex occurs in prematures (see Footnote 7) and in sleep [see Pietrusky (78)]. Bartels (102, pp. 358-359) finds that in prematures the slow phase of vestibular nystagmus occurs, but the quick phase is absent; and Coppez (114, p. 100) states that the two phases of vestibular nystagmus are dissociated in sleeping infants—if the infant is rotated the eyes deviate to the side (the slow phase), but they remain deviated instead of jerking back as they would if the quick phase were present.

Can the quick and slow phases of optic nystagmus be dissociated under conditions similar to those mentioned by Coppez?

The following experiment is undertaken to determine whether or not either the slow or quick phase of optic nystagmus occurs during sleep. If sufficient care is taken, it is possible to hold apart the eyelids of a sleeping infant so that the pupil is exposed, without waking the infant.³³ While the eye is thus exposed an attempt is made to produce optic nystagmus. This is done either by rotating in front of the child a white

³³Dr. Jameson, who collaborated in this experiment, became very skillful in holding the eyelids apart without waking the subject.

covered kymograph drum carrying longitudinal black stripes, or by moving back and forth at a distance of 6 to 8 inches in front of the child's face a piece of white cardboard carrying transverse black stripes.³⁴

Successful trials (i.e., trials in which the stimulus is definitely moved back and forth directly in front of the open eye four or more times while the infant remains asleep) are made on 21 children at the following ages: 1 at 13½ days, 1 at 17 months, 2 at 18, 1 at 19, 1 at 21, 4 at 22, 3 at 23, 2 at 24, 1 at 25, 1 at 26 months, and 4 additional cases at about 19 or 20 months old.

In the successful trials we are *unable to observe a single instance in which there is any indication that eye-movements are produced by this stimulation*. On the other hand, when infants are awakened by the experimental procedure, eye-movements do occur.

From these results we conclude that, in case of sleeping children between 18 and 25 months of age, neither phase of optic nystagmus can be produced by the form of stimulation used by us.

These results, while not conclusive, tend to support the views that this phenomenon does not occur entirely reflexively, that the neural basis is radically different from that of the pupillary light reflex, that the cortex probably plays a part in the production of both phases, and that the neural mechanisms producing both phases of the responses are different for optic and vestibular nystagmus.

³⁴Similar to Borries' Nystagmus Ruler in principle, but somewhat different in construction.

THE DEVELOPMENT OF OCULAR PURSUIT

When we speak of Type II (pursuit) eye-movements in the preceding section, especially in connection with optic nystagmus, we do not mean that the ability to make such eye-movements is the same as the ability to pursue successfully a moving object with the eyes. In fact, the records show definitely that, although the ability to make pursuit eye-movements is present within a few minutes of birth, *none of our subjects is able to pursue successfully a moving object during the first two weeks*. For the sake of clarity it is necessary to state what is meant by successful ocular pursuit. By successful ocular pursuit is meant merely that pursuit movements of the eyes occur in the direction of the moving visual field, that these pursuit movements are very seldom broken by movements in the opposite direction which are large enough to be observed by the unaided eye, and that when the moving object changes its direction of movement the pursuit movements also change in direction, so that the eyes and the moving object are moving in the same direction practically all the time.

Since this definition is not entirely satisfactory, instead of classifying responses as successful pursuit, or unsuccessful pursuit, as many other authors do (see Table 1), we describe the number and the direction of the eye-movements which make up the pursuit.³⁵

During the first two weeks, and even during the first hours after birth, movements of the visual field have a definite effect upon the eye-movements of the infant.

³⁵This is also done by Guernsey (53).

However, during the first few weeks this effect is not an ocular pursuit, but only a tendency toward pursuit. The pursuit is not well sustained, but is broken by movements in the opposite direction interspersed between correctly directed pursuit movements. When the movement of the cylinder changes direction, even during the first two weeks, the direction of the majority of the eye-movements changes to correspond with the direction of movement of the cylinder. At this age pursuit occurs to the extent that the direction of the majority of the eye-movements is dependent on the direction of movement of the object followed. However, the ocular response occurring has more characteristics of optic nystagmus than it has of the response usually spoken of as successful visual pursuit. The eyes tend to follow the moving visual field but do so only for a short distance before the pursuit is broken by jerky ocular movements in the opposite direction.³⁶

Differences between statements in the literature concerning the time of first occurrence of successful ocular pursuit of a moving object are probably due partly to differences in the conditions under which the observations are made. It is possible that the subjects could have followed successfully at an earlier age an object moved at a slower speed or through a shorter angular distance than that used in our experimental situation. On the other hand, the writer believes that many of the great discrepancies between statements in the literature concerning the first occurrence of successful visual

³⁶Gutmann (54) notices the similarity between optic nystagmus and the responses made by certain infants, observed by him, while attempting to pursue a slowly moving light.

pursuit of a moving object are not due to differences in experimental conditions, such as size of object, angular speed, and distance of movement, but are due to the fact that some writers call the type of response described above successful ocular pursuit, while others, including the writer, consider successful ocular pursuit to mean the ability to follow a moving object in the adult fashion.

The most typical characteristics of the earliest successful visual pursuit are that the individual adjustments composing it are rather large,³⁷ making the pursuit very "jerky," and that there is considerable latency between the change in direction of movement of the object pursued and the change in direction of the movement of the eyes.

As the child grows older the pursuit becomes less jerky. That is, the ocular adjustments composing it become more numerous and smaller, resulting in a better correspondence with the motion of the object followed. At the same time the tendency for the eye to lag behind when the moving field changes direction decreases, and movements of the head are used to supplement the eye-movements, with the result that the pursuit becomes more smooth and regular.

The subjects are placed in the experimental situation, and their response to each of two visual fields, one consisting of one black bar on the white cylinder lining, and the other consisting of 10 similar bars on the same background, is recorded. Each of these

³⁷This statement is based on a subjective impression which has not yet been verified by measurements of the films.

TABLE 8

Age in Weeks	Slow speed					Medium speed				
	2	3	Av.	2	3	4	5	6	Av.	
Number of movements of the apparatus										
Percentage correctly directed	57	69	64	58	83	75	98	98	85	
Number correctly directed per movement of the apparatus	1.53	1.83	1.72	.86	1.40	1.14	1.95	2.07	1.51	
Number incorrectly directed per movement of the apparatus	1.17	.81	.95	.61	.29	.37	.03	.05	.26	
Total number in both directions per movement of the apparatus	2.70	2.64	2.67	1.47	1.69	1.51	1.98	2.12	1.77	
Total number in both directions per movement of the apparatus—Range	0-5	0-6	0-6	0-4	0-3	0-4	0-5	0-4	0-5	
Percentage correctly directed	50	92	68	80	95	84	98	98	94	
Number correctly directed per movement of the apparatus	.27	.23	.24	.16	.38	.46	.73	.83	.53	
Number incorrectly directed per movement of the apparatus	.27	.02	.12	.04	.02	.08	.02	.02	.04	
Total number in both directions per movement of the apparatus	.53	.25	.36	.20	.40	.54	.74	.84	.57	
Total number in both directions per movement of the apparatus—Range	0-2	0-1	0-2	0-1	0-2	0-2	0-2	0-2	0-2	
Percentage correctly directed	56	71	65	61	85	78	98	98	87	
Number correctly directed per movement of the apparatus	1.80	2.06	1.96	1.02	1.77	1.59	2.68	2.90	2.04	
Number incorrectly directed per movement of the apparatus	1.43	.83	1.06	.65	.31	.46	.05	.07	.29	
Total number in both directions per movement of the apparatus	3.23	2.90	3.03	1.67	2.08	2.05	2.73	2.96	2.33	
Total number in both directions per movement of the apparatus—Range	0-5	0-7	0-7	0-4	0-5	0-4	0-5	1-5	0-5	
*Coordinate compensatory eye-movements	0	1	1	0	0	1	7	1	9	
†Eye-movements so smooth that the individual jerks cannot be counted	0	2	2	0	4	4	5	2	15	

TABLE 8 (continued)

EYE-MOVEMENTS IN EARLY INFANCY

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Age in Weeks		Fast speed						Totals: medium and fast speeds only					
		2	3	4	5	6	Av.	2	3	4	5	6	Av.
Number of movements of the apparatus		26	55	49	58	61		75	103	108	120	119	
Eye-movements	Percentage correctly directed	71	88	84	90	97	90	61	84	78	95	97	87
	Number correctly directed per movement of the apparatus	.46	.65	.78	1.10	1.21	.90	.72	1.00	.97	1.54	1.63	1.22
	Number incorrectly directed per movement of the apparatus	.19	.09	.14	.12	.03	.10	.47	.18	.27	.08	.04	.18
	Total number in both directions per movement of the apparatus	.65	.75	.92	1.22	1.25	1.00	1.19	1.18	1.24	1.62	1.67	1.41
	Total number in both directions per movement of the apparatus—Range	0-3	0-2	0-2	0-3	0-3	0-3						
Head-movements	Percentage correctly directed	100	100	96	88	97	95	85	97	89	95	97	94
	Number correctly directed per movement of the apparatus	.12	.27	.45	.26	.46	.33	.15	.32	.45	.50	.64	.44
	Number incorrectly directed per movement of the apparatus	.00	.00	.02	.03	.02	.02	.03	.01	.06	.03	.02	.03
	Total number in both directions per movement of the apparatus	.12	.27	.47	.29	.48	.35	.17	.33	.51	.52	.66	.46
	Total number in both directions per movement of the apparatus—Range	0-1	0-1	0-2	0-1	0-1	0-2						
Totals: Head- and Eye-movements	Percentage correctly directed	75	91	88	90	97	91	64	87	81	95	97	89
	Number correctly directed per movement of the apparatus	.58	.93	1.22	1.36	1.67	1.23	.87	1.32	1.43	2.04	2.27	1.66
	Number incorrectly directed per movement of the apparatus	.19	.09	.16	.16	.05	.12	.49	.19	.32	.10	.06	.21
	Total number in both directions per movement of the apparatus	.77	1.02	1.39	1.52	1.72	1.35	1.36	1.51	1.75	2.14	2.33	1.87
	Total number in both directions per movement of the apparatus—Range	0-3	0-2	0-3	0-3	1-4	0-4						
*Coordinate compensatory eye-movements		0	0	0	1	0	1	0	0	1	8	1	10
†Eye-movements so smooth that the individual jerks cannot be counted		0	2	2	1	2	7	0	6	6	6	4	22

*Omitted in other parts of the table.

†Counted as one in other parts of the table.

fields is moved at each of three speeds during the first three weeks; and beyond the third week, at two different speeds.

A detailed study of the moving picture records is made. Each portion of the record is studied several times, and all the head- and eye-movements which can be observed in the moving pictures are recorded, along with the direction of movement of the stimulus at the time.

Table 8 shows the number of movements of the apparatus, the number of ocular movements in the direction of movement of the visual field, the number of ocular movements in the opposite direction, and the number of head-movements in each direction, per movement of the apparatus. It also gives the number of pursuit movements so smooth that the individual adjustments cannot be counted and the number of coordinate compensatory eye-movements which occur in response to the movements of the apparatus. The table gives these data for the second, third, fourth, fifth, and sixth weeks. (The number of responses during the first week is not sufficiently large to justify statistical treatment.) In addition, Table 8 gives several averages, percentages, and ranges, which are based on the figures mentioned above.

The weekly averages for the medium and fast speeds taken together, in Table 8, show that the number of ocular movements in the direction of movement of the apparatus, per movement of the apparatus, increases regularly week by week, more than doubling between the second and sixth weeks, while the number of eye-movements in the opposite direction is decreasing, the

average for the sixth week being less than one-tenth as large as the corresponding average for the second week. During the same period the total number of eye-movements in both directions also increases gradually. Table 9 furnishes data which indicate that the differences between the average number of eye-movements, in the direction of movement of the apparatus, for ages differing by more than one week are highly reliable, and thus support the interpretation that the differences are real changes brought about by age and experience.

The weekly percentage of eye-movements which correspond in their direction with the direction of movement of the visual field also increases gradually from the second to the sixth week, with the exception of one slight inversion at the third and fourth weeks.

The number of head-movements in the same direc-

TABLE 9

RELIABILITY OF THE DIFFERENCES BETWEEN THE AVERAGE NUMBER OF CORRECT EYE-MOVEMENTS, PER MOVEMENT OF THE APPARATUS, FOR VARIOUS AGES

(Results at medium and fast speeds averaged together.)

Weeks	Difference	<i>S.D.</i> <i>Diff.</i>	<i>Diff.</i>	Chances in .100 of a true difference greater than zero
			<i>S.D.</i> <i>Diff.</i>	
6 and 5	.07	.124	.57	71
6 and 4	.66	.106	6.22	100
6 and 3	.63	.117	5.38	100
6 and 2	.91	.122	7.46	100
5 and 4	.57	.125	4.56	100
5 and 3	.54	.135	4.00	100
5 and 2	.82	.139	5.90	100
4 and 3	.03	.119	.25	60
4 and 2	.25	.123	2.03	98
3 and 2	.28	.133	2.10	98

tion as the movement of the visual field, per movement of the apparatus, increases gradually between the second and sixth weeks, and the percentage of head-movements in the correct direction also increases, although less consistently. By the sixth week the number of head-movements, per movement of the apparatus, corresponding in their direction with the movements of the apparatus are more than four times as numerous as they are in the second week.

The number of head-movements in the direction opposite the direction of movement of the apparatus, the number of pursuit movements which are so smooth that the individual movements which compose them cannot be counted, and the number of coordinate compensatory eye-movements are all so small that the figures based on them have little meaning.

Table 8 also shows that the average number of head- and eye-movements in the correct direction, per movement of the apparatus, for the medium and fast speeds taken together, increases regularly from the second through the sixth week, while at the same time the total number of head- and eye-movements (correct and incorrect), per movement of the apparatus, increases. The percentage in the correct direction increases less regularly, and the number of incorrectly directed head- and eye-movements decreases (also less regularly) at the same time.

THE EFFECT ON OCULAR PURSUIT OF THE SPEED OF THE OBJECT FOLLOWED

The speed of movement of the object followed exerts a definite influence on the number of eye-move-

ments which occur during pursuit. Table 10, which is based on the results of experimentation during the second and third weeks, shows that the number of eye-movements, which occur in the direction of movement of the apparatus per movement of the latter at the slow speed, is about 3 times as great as the number of corresponding movements occurring in response to the fast speed of movement of the apparatus, and over 1.5 times as large as the number made in response to the medium speed of movement of the apparatus. The reliabilities of the differences just mentioned have been calculated, and all the differences are highly reliable. (The smallest value of the difference divided by the sigma of the difference is 3.5.)

The rows entitled "Eye-Movements: Number correctly directed per movement of the apparatus," in the columns in Table 8 which have the captions "Medium Speed—Average" and "Fast Speed—Average" show similarly that more correct eye-movements occur per movement of the apparatus at the medium than at the fast speed during the period from the second through the sixth week. Again, the difference between the number of eye-movements correctly directed at the two speeds is highly reliable—the difference divided by the sigma of the difference being 7.8.

However, Table 10 shows that the number of eye-movements per movement of the apparatus which do not correspond with the direction of movement of the latter is also much greater at the slower than at the faster speeds of the apparatus. In fact the percentage of eye-movements which correspond in direction to the

TABLE 10
TOTALS: SECOND AND THIRD WEEKS ONLY

	Eye-movements			Head-movements			Head- and eye-movements		
	Slow speed	Medium speed	Fast speed	Slow speed	Medium speed	Fast speed	Slow speed	Medium speed	Fast speed
Number of movements of the apparatus	78	97	81	78	97	81	78	97	81
In the direction of movement of the apparatus	134	109	48	19	26	18	153	135	66
Opposite the direction of movement of the apparatus	74	44	10	9	3	0	83	47	10
Total number in both directions	208	153	58	28	29	18	236	182	76
Percentage correctly directed	64	71	83	68	90	100	65	74	87
Number correctly directed, per movement of the apparatus	1.72	1.12	.59	.24	.27	.22	1.96	1.39	.82
Number incorrectly directed, per movement of the apparatus	.95	.45	.12	.12	.03	.00	1.06	.48	.12
Total number in both directions, per movement of the apparatus	2.67	1.58	.72	.36	.30	.22	3.03	1.88	.94

movements of the apparatus is greatest (83%) at the fast speed, next (71%) at the medium speed, and least (64%) at the slowest speed. Similarly, Table 8 shows that for the period from the second through the sixth week, 90% of the eye-movements are in the correct direction at the fastest speed, and only 85% at the medium speed.

These facts suggest that responses to different speeds of the apparatus cannot be adequately compared by merely stating the number and direction of the eye-movements which occur, but that data concerning the extent of the ocular movements are necessary before one can compare the relative adequacy of ocular pursuit in response to different speeds of the object followed. Also the additional data just mentioned would be useful, although not so essential, when comparing different responses made to one speed of the apparatus, especially when the responses are made at different ages.

The first portion of Table 10 also shows the total number of eye-movements in both directions at each speed, for the second and third weeks; and the columns in Table 8 which have the captions "Medium Speed—Averages" and "Fast Speed—Averages" give similar data for the medium and fast speeds for the period from the second through the sixth week.

The findings with respect to the number of eye-movements occurring during the different speeds of ocular pursuit agree with the findings concerning the number of eye-movements which occur during optic nystagmus produced by various speeds of movement of the appa-

TABLE 11

	Slow speed				Medium speed				Fast speed				Medium and fast speeds			
	Bar	Group	Bar	Group	Bar	Group	Bar	Group	Bar	Group	Bar	Group	Bar	Group	Bar	Group
Number of movements of the apparatus	38	40	133	143	128	121	261	264								
Percentage in the direction of movement of the apparatus																
Eye-movements																
Number in the direction of movement of the apparatus, per movement of the apparatus	65	63	83	87	88	92	85	89								
Total number in both directions, per movement of the apparatus	1.84	1.60	1.42	1.59	.88	.93	1.15	1.29								
Percentage in the direction of movement of the apparatus	2.82	2.52	1.71	1.83	1.00	1.01	1.36	1.45								
Head-movements																
Number in the direction of movement of the apparatus, per movement of the apparatus	69	67	92	95	92	100	92	96								
Total number in both directions, per movement of the apparatus	.29	.20	.43	.62	.34	.32	.39	.48								
Percentage in the direction of movement of the apparatus	.42	.30	.47	.66	.38	.32	.42	.50								
Head-and-eye-movements																
Number in the direction of movement of the apparatus, per movement of the apparatus	66	64	85	89	89	94	86	91								
Total number in both directions, per movement of the apparatus	2.13	1.80	1.85	2.22	1.22	1.25	1.54	1.77								
Percentage in the direction of movement of the apparatus	3.24	2.82	2.18	2.48	1.37	1.33	1.78	1.95								

TABLE 12

DATA CONCERNING THE RELIABILITY OF THE DIFFERENCES BETWEEN THE AVERAGE NUMBER OF EYE-MOVEMENTS PER MOVEMENT OF THE APPARATUS FOR THE SINGLE BAR AND FOR THE GROUP OF BARS

Speed of movement of apparatus	Averages based on data from the second through the sixth week		Difference	<i>S.D.</i> <i>Diff.</i>	<i>Diff.</i> <i>S.D.</i> <i>Diff.</i>		Chances in 100 of a true difference greater than zero
	Bar	Group of bars					
Medium	1.42	1.59	.170	.130	1.31		90
Fast	.88	.93	.501	.094	.54		71
Totals							
Medium and fast	1.15	1.29	.135	.084	1.61		94

tus. That is, in both types of response the number of ocular movements increases with the time taken by the movement of the apparatus, and hence bears an inverse relationship to the speed of movement of the apparatus.

Table 11 shows that, in general, and with numerous exceptions, the number of eye-movements in the direction of movement of the apparatus, per movement of the apparatus, is slightly higher, and the percentage of eye-movements in the direction of movement of the apparatus which occur in response to the movements of the visual field of 10 bars is also slightly larger than the number and the percentage of correct eye-movements which occur in response to the movements of the visual field consisting of a single bar. The data in Table 12, however, indicate that the small and inconsistent differences just mentioned are not highly reliable.

IV

SUMMARY AND CONCLUSIONS

During this investigation the six regular subjects respond favorably to the experimental situation, and over 3000 feet of 16-mm. moving picture records of their responses are secured under carefully controlled conditions.

The number of subjects is too limited to permit broad generalizations concerning such matters as the average age at which visual pursuit first occurs, but the data do justify the following definite conclusions:

OPTIC NYSTAGMUS AND EYE-MOVEMENTS

1) Optic nystagmus occurs the first time each subject opens his eyes in the experimental situation while the cylinder is rotating at slow or medium speeds (even during the first 12 hours after birth, and even in an infant who is born one month prematurely):

2) Both the large saccadic eye-movements, which make up the quick phase of optic nystagmus, and the slow, gliding, pursuit movements (composed of several small saccadic movements), which make up the slow phase, occur during the first occurrence of optic nystagmus.

3) A few coordinate compensatory eye-movements occur within a few days of birth, but they occur too infrequently to permit any further generalizations concerning them.

4) The technique used on sleeping infants fails to produce optic nystagmus.

5) The number of eye-movements occurring during optic nystagmus is influenced by the number and the speed of movement of the bars on the visual field, and also, but to a smaller degree, by the age and experience of the child.

OCULAR PURSUIT

1) Successful ocular pursuit is not exhibited by any subject during the first two weeks of life. However, before ocular pursuit is possible (even in the first two weeks), the majority of the movements of the infant's eyes occur in the direction of the movement of the stimulating object; but many eye-movements in the opposite direction occur.

2) With increasing age there is a gradual increase in the number of eye-movements corresponding in direction with the movements of the stimulating object, and a gradual decrease in the number of movements in the opposite direction.

3) At the same time there is a marked increase in the number of head-movements occurring in the direction of the movement of the stimulus.

4) All the subjects, when six weeks old, are able to respond to the movements of the apparatus with an ocular pursuit which has many of the characteristics of the ocular pursuit of an adult, and which is practically free from gross ocular movements which do not correspond with the movements of the stimulus. (Non-corresponding movements make up only 5.5% of the total number at 5 weeks, and only 3.1% at 6 weeks.) Ocular pursuit first appears in the subjects during the third and fourth weeks.

5) The number of ocular adjustments during pursuit of a moving object under our experimental conditions is inversely related to the speed of movement of the apparatus (as is true in the case of optic nystagmus); but, under conditions otherwise comparable, the proportion of eye-movements in the correct direction is usually greater for the rapid speed than for slower speeds of the apparatus.

6) Inasmuch as the number of eye-movements occurring during optic nystagmus is only influenced to a relatively slight degree by the age and experience of the child, and inasmuch as age and experience produce a pronounced effect on the infants' ocular pursuit of a moving visual field, the investigation of the latter ability appears to offer greater value for normative studies of infant development than does the study of optic nystagmus.

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LES MOUVEMENTS DES YEUX ET LE NYSTAGMUS OPTIQUE
DANS LA PREMIÈRE ENFANCE

(Résumé)

Pendant les six premières semaines suivant la naissance on procure des données cinématographiques, à des intervalles réguliers, de six enfants humains. On synchronise les enregistrements des réponses résultantes avec les enregistrements des mouvements de l'appareil lesquelles on obtient pendant qu'un champ visuel composé d'une surface cylindrique blanche traversée par des barreaux noirs en travers fait un mouvement rotatoire devant les sujets à une de trois vitesses; et pendant que chacun de deux champs visuels est oscillé devant les sujets à trois vitesses. Le premier champ visuel se compose d'un seul barreau noir sur un fond blanc, et le second de dix barreaux semblables sur un fond semblable.

Un nystagmus optique typique a lieu la première fois que chaque sujet ouvre les yeux dans la situation expérimentale pendant la rotation du champ visuel barré, quand même le sujet ne serait âgé que de quelques heures ou de quelques jours.

Il se trouve une correspondance assez exacte entre les mouvements saccadés des yeux, lesquels forment la phase rapide du nystagmus optique, et la position des barreaux sur le champ visuel rotatoire. Le degré de correspondance est le plus grand à la vitesse moyenne et le moindre à la vitesse rapide de l'appareil.

Quand on tient ouvertes les paupières d'un oeil d'un enfant qui dort et qu'on stimule la rétine par un champ visuel en mouvement qui produit le nystagmus optique chez l'enfant éveillé, aucun enfant qui dort ne montre cette réponse.

Les mouvements saccadés et ceux de poursuite ont lieu dans le nystagmus optique pendant les réponses des plus jeunes enfants; et des mouvements coordonnés compensatoires des yeux, lesquels sont relativement rares pendant les premières semaines, se trouvent quelquefois en quelques jours après la naissance.

Cependant, il ne se trouve aucune poursuite oculaire réussie pendant les deux premières semaines après la naissance. Pendant la deuxième semaine la plupart des mouvements des yeux (à peu près 60%) se trouvent dans la direction du mouvement du champ visuel, mais des mouvements des yeux en sens opposé à la direction du mouvement du champ visuel se trouvent entremêlés entre les mouvements correctement dirigés, et la réponse qui résulte ne peut être appelée précisément une poursuite réussie.

Avec l'accroissement de l'âge, il se trouve un accroissement graduel du nombre des mouvements des yeux et de la tête lesquels ont lieu à chaque oscillation du champ visuel et il y a aussi un accroissement graduel de la proportion des mouvements des yeux et de la tête correctement dirigés; mais en même temps le nombre et la proportion des mouvements des yeux dans la direction opposée au mouvement du champ visuel se décroissent graduellement. Ces effets de l'âge sur la poursuite oculaire présentent un contraste frappant avec l'effet relativement léger de l'âge sur le nystagmus optique.

Le nombre des mouvements des yeux ayant lieu à chaque mouvement du champ visuel oscillé a un rapport inverse avec la vitesse de l'oscillation de celui-ci, mais la proportion des mouvements des yeux dans la direction de poursuite a un rapport direct avec la vitesse du champ visuel. Ce résultat-ci suggère que la proportion des mouvements des yeux dans la direction de poursuite n'est pas une mesure adéquate de l'efficacité relative de

la poursuite oculaire de champs visuels mis en motion à des vitesses différentes, mais a besoin aussi de données supplémentaires, telle que la longueur exacte des mouvements oculaires individuels.

En moyenne, un nombre un peu plus grand de mouvements des yeux pour chaque mouvement de l'appareil et un pourcentage un peu plus grand de mouvements des yeux dans la direction de poursuite ont lieu en réponse aux mouvements du champ visuel de dix barreaux qu'en réponse aux mouvements du champ visuel d'un seul barreau mais la différence entre les réponses moyennes dans les deux situations est petite, et n'est par très constante.

McGINNIS.

AUGENBEWEGUNGEN UND OPTISCHER NYSTAGMUS IM FRÜHEN SÄUGLINGESALTER

(Referat)

Man machte Kinaufnahmen von sechs Säuglingen in regelmässigen Intervallen während der ersten sechs Wochen nach der Geburt. Die Aufnahmen der Reaktionen wurden synchronisiert mit den Aufnahmen der Apparatbewegungen. Man machte die Aufnahmen, währenddem ein Gesichtsfeld, das aus einer weissen zylindrischen Oberfläche bestand und von schwarzen Stäben traversiert wurde, vor den Versuchspersonen in einer von drei Geschwindigkeiten rotierte, und währenddem jedes der zwei Felder vor der Versuchsperson in drei Geschwindigkeiten oszillierte. Das erste Gesichtsfeld besteht aus einem einzigen schwarzen Stab auf einem weissen Hintergrund, und das zweite besteht aus zehn ähnlichen Stäben auf einem ähnlichen Hintergrund.

Es zeigt sich jedesmal ein typisch optischer Nystagmus, wenn eine Versuchsperson die Augen während der Rotation des Gesichtsfeldes öffnet, sogar wenn die Versuchsperson nur ein paar Stunden oder Tage alt ist.

Es besteht eine grobe Übereinstimmung zwischen den ruckartigen Augenbewegungen, die die schnelle Phase des optischen Nystagmus bilden, und der Stabstellungen auf dem rotierenden Gesichtsfeld. Der Grad der Übereinstimmung ist am grössten bei der mittleren, und am geringsten bei der grossen Geschwindigkeit des Apparates.

Wenn das eine Augenlid eines schlafenden Säuglings offen gehalten und die Netzhaut durch ein rotierendes Gesichtsfeld gereizt wird, das einen optischen Nystagmus beim wachen Kinde hervorruft, so zeigt keiner der schlafenden Säuglinge diese Reaktion. Ruckhafte und verfolgende Augenbewegungen zeigen sich im optischen Nystagmus bei Reaktionen der jüngsten Säuglinge; und koordinierte kompensierende Augenbewegungen, die sich während der ersten paar Wochen verhältnismässig wenig häufig ereignen, zeigen sich hie und da während der ersten paar Tage nach der Geburt.

Andererseits zeigt sich während der zwei Wochen nach der Geburt keine erfolgreiche Verfolgungsbewegung. In der zweiten Woche ist die Mehrzahl der Augenbewegungen (ungefähr 60%) der Bewegung des Feldes gleichgerichtet, aber die der Bewegung des Gesichtsfeldes entgegengerichteten Augenbewegungen sind zwischen die korrekten Bewegungen eingestreut; und die erfolgende Reaktion kann nicht mit Recht eine erfolgreiche Verfolgung genannt werden.

Mit zunehmendem Alter ergibt sich eine allmähliche Zunahme der Augen-

und Kopfbewegungen pro Schwingung des Gesichtsfeldes, ferner ergibt sich eine allmählich proportionale Zunahme der richtig gerichteten Augen- und Kopfbewegungen; gleichzeitig aber nehmen die Zahl und das Verhältnis der der Bewegung des Gesichtsfeldes entgegengesetzten Bewegungen allmählich ab. Diese Einflüsse des Alters bezüglich der Sehverfolgung sind im auffallenden Gegensatz zum verhältnismässig geringen Einfluss des Alters beim optischen Nystagmus.

Die Zahl der Augenbewegungen pro Schwingung des Gesichtsfeldes steht im umgekehrten Verhältnis zur Schwingungsgeschwindigkeit des letzteren, aber das Verhältnis der Augenbewegungen in der Richtung der Verfolgung hat eine direkte Beziehung zur Geschwindigkeit des Gesichtsfeldes. Das letztere Ergebnis weist darauf hin, dass das Verhältnis der Augenbewegungen in der Verfolungsrichtung kein hinreichendes Mass der relativen Leistungsfähigkeit bezüglich der Augenbewegungen, ist die das sich verschieden schnell sich bewegende Gesichtsfeld verfolgen, sondern dass dieses Ergebnis ergänzt werden muss durch andere Angaben, wie z. B. über die genaue Länge der individuellen Augenbewegungen.

Durchschnittlich zeigen sich eine ein wenig grössere Anzahl der Augenbewegungen pro Apparatbewegung und ein ein wenig höherer Prozentsatz der Augenbewegungen in der Verfolungsrichtung bei einem Gesichtsfeld mit zehn Stäben, als bei einem Gesichtsfeld mit einem Stab. Der Unterschied ist aber gering und nicht sehr zuverlässig.

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